CHARACTERISTIC PERFORMANCE

OF

AN INDUCTION GENERATOR

BY

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Armour Institute of Technology

1908

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CHARACTERISTIC PERFORMANCE

OF

AN INDUCTION GENERATOR

A THESIS

PRESENTED BY

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V. E. LAURENCE
E. W. ADAMS

TO THE

PRESIDENT AND FACULTY

OF

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INTRODUCTION

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Until recently the induction or non- synchronous generator has been regarded more as a scientific curiosity than as a possible rival to the well known synchronous generator.

Nearly a quarter of a century ago a prominent French engineer, M. Le Blanc, demonstrated that under certain conditions an induction motor would return power to the line when driven above synchronous speed. He found that in addition to the speed requirement above mentioned, the induction generator required for its excitation a source of watt-less or magnetizing current, and furthermore that the current must lead the E.M.F. of the system before the induction motor would act as a generator.

In view of the fact that these conditions made the induction generator impractical at that time, Mr.LeBlanc's work was almost forgotten. Although from time to time different investigators experimented with the induction generator, it was not until 1895, when Mr. B. G. Lamme proposed running an induction generator in connection with an unloaded synchronous motor, that the induction generator was made a commercial possibility. His idea was that the generator would furnish the power component of the current of the system, and the motor the wattless

component. This proposal led to further experimenting, and it was demonstrated that the induction generator would operate satisfactorily in connection with a synchronous motor or convertor, and that by means of the motor excitation the voltage of the system could be regulated. The synchronous generator was, however, giving such general satisfaction at that time that the induction generator was once more laid away on the shelf.

About this time other investigators, namely, Messrs. Stanley and Heyland, made a series of experiments with specially constructed machines operating on the principal of the induction generator. However, as these machines lost all semblance to the squirrel cage induction motor, owing to the addition of special windings, commutators, and devices, they can hardly be classed with the induction generator.

Recently the induction generator has been brought before the engineering world by Mr. W.L. Waters, who, in a paper given before the American Institute of Electrical Engineers, February, 1908, calls attention to the fact that the induction generator is not only a commercial possibility, but that there are in this country actual installations of induction generators, which have been operating successfully for some time. Mr. Waters points out that conditions at present are most favorable for

the more extended use of this type of generator, owing to the present extensive use of synchronous motors and converters in large distributing systems. Furthermore as one of the characteristics of the induction generator is that it has no definite voltage, the voltage depending upon the system supplied, the induction generator may be subjected to considerable variation of speed, without affecting the voltage regulation. The fact that close speed regulation is not essential, makes the induction generator particularly available for use, direct connected to steam turbines or gas engines, where the speed regulation is comparatively poor. Inasmuch as the steam turbine and the gas engine are coming into extensive use, the future of the induction generator is especially promising at this time.

In collecting the available data on the induction generator, we found that while several investigators had experimented with this type of generator, comparatively few had experimented extensively along the lines of commercial operation, that is, while the effect of speed, frequency, etc., had been thoroughly investigated, we were unable to find complete data or curves showing the performance of the induction generator under the conditions it would have to meet when installed for commercial

operation. Because of this dearth of data, we decided to run the test, the results of which are hereinafter presented. We determined to make the conditions of the test, as nearly as our facilities would permit, those under which the induction generator would have to operate in a central station.

METHOD of PROCEEDURE

The generator used was available through the courtesy of the General Electric Company, who furnished us with one of their standard 220 volt, 60 cycle, 25 H.P., squirrel cage induction motors. We arranged to drive this motor as a generator, by means of a direct current motor, through a belt connection, with a pulley ratio of four to one. For excitation we used a 10 K.W. General Electric, 120 Volt, 60 cycle revolving field alternator, operating it as a synchronous motor. This machine was so arranged that it could be sufficiently over excited to maintain the system voltage at two hundred. Owing to the excessive field current necessary to obtain this voltage, the heating of the synchronous motor fields precluded our operating at the rated voltage of the induction generator. This heating was overcome in a measure by means of a motor driven blower, so arranged as to force a blast of cool air upon the revolving field coils.

The scheme of connections used, with slight modifications, throughout the entire test, is shown in detail on accompanying wiring diagrams, and is substantially as follows:

The synchronous motor or exciter is connected

to a 10 K.W. synchronous generator. A two pole double throw switch is arranged to open two of the phase lines between generator and motor. This combination of synchronous motor and generator is used only in starting. The synchronous motor is also connected in parallel with the load terminals of the induction generator. A three pole double throw switch at the induction generator provides means for cutting off both the synchronous motor and load from the induction generator. This switch is also provided with 75 amp. fuses for protection. The load, which in all except one run is non-inductive, consists of lamps connected star. The star connection was used because the available wattmeters were designed for 150 volts, which made it impossible to connect across phases, as would be necessary in a delta, the voltage across phases being 200. In a star connection the voltage from phase line to neutral is two hundred over the square root of three, or about one hundred sixteen, which voltage is within the limits of the wattmeters.

The arrangement of instruments is as follows: Three Thompson ammeters placed in the leads at the induction generator measure the current per phase line at the generator. A voltmeter and frequency-meter is so arranged that it can be thrown across two phase lines of either

the induction or synchronous generator, by means of a two-pole double-throw switch. In the exciter circuit the series coil of a wattmeter and an ammeter are connected in one phase line, and the pressure coil of the wattmeter is connected from phase line to neutral, so that the total power in the circuit is equal to three times the wattmeter indication. This is true only on a balanced load and we found that the error introduced by considering the synchronous motor a balanced load is within the limit of experimental error. At the lamp load a single wattmeter in connection with a special transferring switch indicates the power delivered to the load. By means of this switch, the series coil of the wattmeter is transferred from phase line to phase line while at the same time one side of the pressure coil was also transferred. The other side of the pressure coil is permanently connected to neutral. The necessary modifications of the above arrangement used with the runs in which a non-inductive load is used are shown on plates No. 1 and No. 2.

In order to measure the rotor speed and slip a special device, consisting of an interupter and frequency meter, was used. This device is shown diagramatically on plate No. 3. The interrupter is provided with a

threaded stud which fits in a hole tapped in the end of the rotor shaft. This interrupter is made in two sections placed side by side. One section forms a continuous conducting ring and the other is divided into four segments by means of fibre insulation. Two copper brushes are provided, one of which bears on the continuous ring and the other on the segments. These brushes form part of a circuit consisting of a Hartman and Braun frequency meter and a contact key connected to 110 volt mains. When the upper brush is on a conducting segment a circuit is formed from positive line through the lower brush to the continuous ring, thence to the conducting segment, to the frequency meter, and through the contact key to the negative side of the line. This circuit is made and broken four times for every revolution of the device and as there are four segments, there are four impulses per revolution, passing through the frequency meter. These impulses are registered on the frequency meter as alternations. For instance, at synchronous speed, 1200 R.P.M., there will be 1200 x 4 = 4800 impulses per minute, which will correspond to 80 alternations per second, and in this case the frequency meter will register at eighty. At any other speed the indication on the frequency meter will be directly proportional

to the speed. The contact key is inserted as an additional protection for the frequency meter. This method of measuring speed was determined upon because of its simplicity, its indicating feature, and because no calibration is required.

In order that our results might be as reliable as possible we calibrated all instruments used, and the calibration curves for same are included in this report. The various wattmeters were compared with a Weston laboratory standard voltmeter, which had been previously calibrated with a standard potentionmeter, and a similar standard ammeter. The calibration was made by means of two separate sources of direct current, one source connected to the pressure coil, across which the standard voltmeter, was placed, and the other through a reversing commutator to the series coil and standard ammeter. A comparison of the wattmeter indication and the product of the average ammeter and voltmeter readings was taken as the calibration.

As an A. C. standard ammeter was not available, a dynamometer was first compared with the D. C. standard ammeter and the A. C. ammeters, used on a source of alternating current, were compared with the dynamometer.

As mentioned in the introduction it is necessary that there be a wattless current present in the system before the induction generator can be made to generate; that is in our specific case it was necessary that the synchronous motor exciter should be operating and furnishing the necessary wattless current before the induction generator was connected to the system. In order to bring about this condition the starting synchrenous generator before mentioned was started by means of a direct connected D. C. motor. Before the voltage of this machine was brought up, the synchronous motor was connected in. At this low voltage the synchronous motor operated as an induction or hysterisis motor. The voltage of the alternator was then gradually increased until full line voltage and frequency was reached, at which point the field of the synchronous motor was thrown on, causing it to operate as over excited synchronous motor thus furnishing the required wattless current. When the above conditions had been obtained the induction generator was brought up to a speed which would make its frequency slightly higher than that of the synchronous motor. The switch between the induction generator and synchronous motor was then closed and immediately after the switch, connecting the starting alternator and the synchronous motor, was opened. This left the combination desired, that is, the induction generator furnishing the power current necessary to drive the synchronous motor and the synchronous motor furnishing the wattless current necessary

to excite the induction generator. After fixing the system voltage by adjusting the field of the synchronous motor, the load was then thrown on.

The first actual test made was the determination of the magnetization or no load characterization. To determine this characteristic we operated the generator without load, other than that necessarily imposed by the synchronous motor, and obtained the voltage across phases corresponding to various values of wattless current. The necessary variation of wattless current was obtained by a manipulation of the rheostat in the synchronous motor field. There is of course some question as to whether a true magnetization characteristic can be obtained in this manner, as it is impossible to get no load conditions on the induction generator. However, the load consists of the power required to drive the synchronous motor, which is very small, so that we are justified in considering the voltage under these conditions as the true no load voltage.

Having obtained the magnetization characteristic, we began the main portion of the test, namely the determination of the load characteristics of the induction generator under various conditions.

Run #2 is probably the most important run, in that in this run actual operating conditions were most nearly obtained. The circuits for this run are shown on plate #1. The voltage across phases was kept constant at 200 and the rotor speed

at 1200 R.P.M. The load, which wasnon-inductive was added in small increments until full rated load on the generator was reached. For each increment of load the following quantities were observed; line currents, exciter currents, exciter power, and power to load. From these observations the complete performance of the generator was calculated.

Run #3 was practically a reptition of run #2, with the exception that the system frequency was kept constant at 60 cycles, which necessitated a variation of the rotor speed. The same circuits and observations apply to this run as in the previous run.

The object of run #4 was to determine the effect of the operating voltage on the generator performance. With this in view we operated the generator at 110 volts, 60 cycles, with constant roter speed, and as in the previous runs, obtained the load characteristics.

The object of run #5 was to determine the effect of change of frequency on the generator performance. This run was conducted in the same manner as the next previous run, with the exception that that the system frequency of no load was 50 cycles instead of 60 cycles. The same characteristics were obtained as beforeq and were compared with those obtained at 60 cycles.

In run #6 the character of the load was changed, that is, a synchronous motor generator set was used as load.

We endeavored to keep the load inductive by keeping the excitation of the synchronous motor generator set as low as possible, and the results obtained show that at least during a considerable portion of the run the load was inductive. The variation of the load was obtained by placing a lamp load on the D. C. end of the motor generator set. The constants for this run were, line voltage 200 and rotor speed 1200 R.P.M.

Run #7 was rather in the nature of an experiment and can hardly be classed as one of operating conditions. A motor generator set was used for load as in the preceeding run, and after the system voltage had been adjusted at 200, at no load, the field rheostats of both the synchronous motor exciter and synchronous motor generator were left in the position giving 200 volts, and remained unchanged throughout the entire run. In this manner we maintained the excitation of the unduction generator approximately constant throughout the run. The rotor speed was also kept constant at 1200 R.P.M. As the load was thrown on the motor generator set, the system voltage gradually dropped until at a certain load the induction generator ceased to generate and the synchronous exciter and motor generator came to a standstill.

Run #8 is particularly interesting in that it demonstrates one advantageous characteristic of the induction generator, namely its facility of operation in parallel with

synchronous generating machinery. The scheme of connections used is different from those of previous runs, in that the synchronous motor exciter is not used. The wiring diagram for this run is shown on plate #1. A lamp load was first placed on the synchronous generator. The induction generator was then operated at a speed lower than that necessary to give a frequency of 60 cycles, the frequency of the synchronous generator, and was then thrown in parallel with the synchronous machine. The speed of the induction generator was then gradually raised until the induction generator was carrying the entire load. At the intermediate speeds the division of load between the synchronous and induction generators was noted.

Run #9 consisted of a heat test, in which run the induction generator was operated at full non-inductive load for a period of four consecutive hours. Four Centigrade thermometers were used to measure the temperature rise at various parts of the machine. One of these measured room temperature, another was placed upon the stator laminations, and another in the ventilating ducts, to measure approximately the rotor temperature. The remaining thermometer was inserted in the stator windings. The thermometer bulbs were wrapped in small pieces of cotton waste, and the thermometers were held in their respective positions and protected from vibration by cushions of putty.

In order to obtain the complete performance of an induction generator it is necessary to obtain certain machine data. All such data has been classed under the head of miscellaneous data. The determination of the stator and rotor resistances is included under this head. The stator resistance was measured by the fall of potential method with D. C. instruments and was afterward reduced to the equivalent single phase quantity. The rotor resistance cannot be measured directly, but the resistance as referred to the stator can be obtained from a consideration of the transformer features of the induction motor. The ordinary motor connections were used, and the rotor was clamped in position. A source of A.C. was used, and its potential adjusted so that full load current, as indicated by an ammeter, was flowing in the stator windings. The power imput under these conditions was measured by means of a wattmeter in connection with a transferring switch. The power imput thus obtained represents the copper losses of both rotor and stator at full load. As the stator resistance is known from the previous measurement, the stator copper loss may be calculted, and when substracted from the total loss will give the rotor copper loss. The rotor copper loss divided by the square of the stator current will give the equivalent rotor resistance as referred to the stator.

In order to obtain the rotor current from the circle diagram, the explanation of which will be taken up later,

it is necessary to obtain the no load observations of the induction generator when operating as a motor. For this reason we operated the machine as a motor, and obtained the no load observations at 200 volts, 60 cycles, 110 volts, 60 cycles, 180 volts, 60 cycles, and 110 volts 50 cycles.

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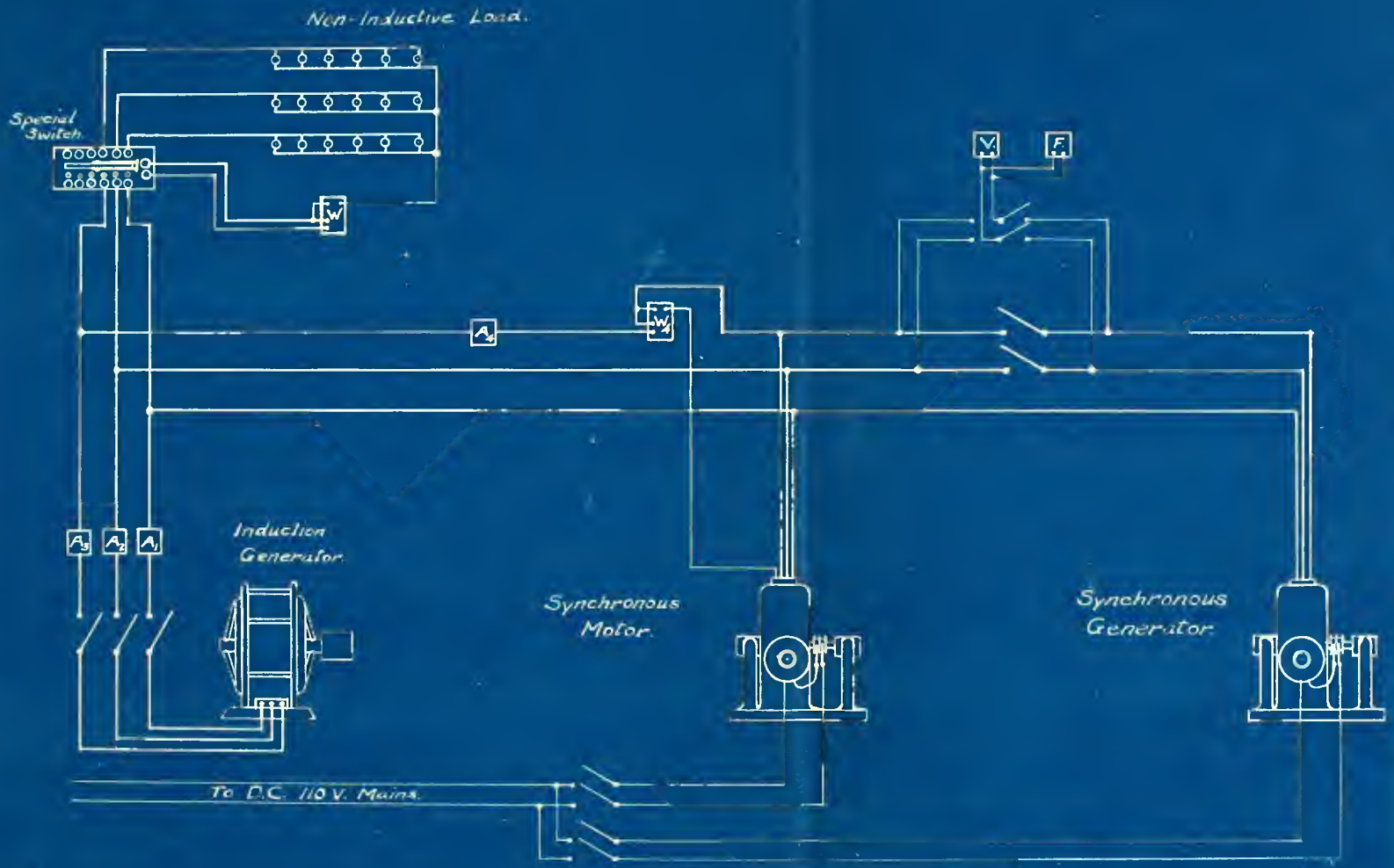
Non-Inductive Load.
Special Switch.
W
V
F
A
W
A3
A2
A1
Induction Generator.
Synchronous Motor.
Synchronous Generator.
To D.C. 110 V. Mains.

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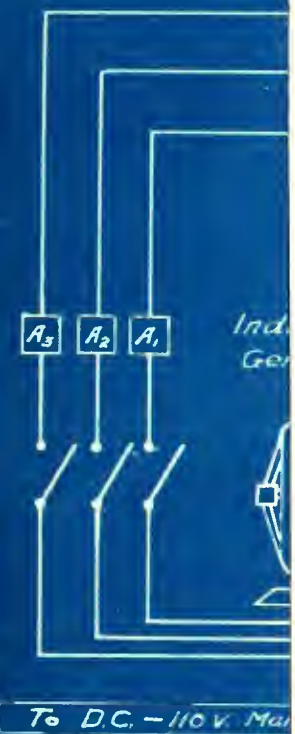

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PLATE II.

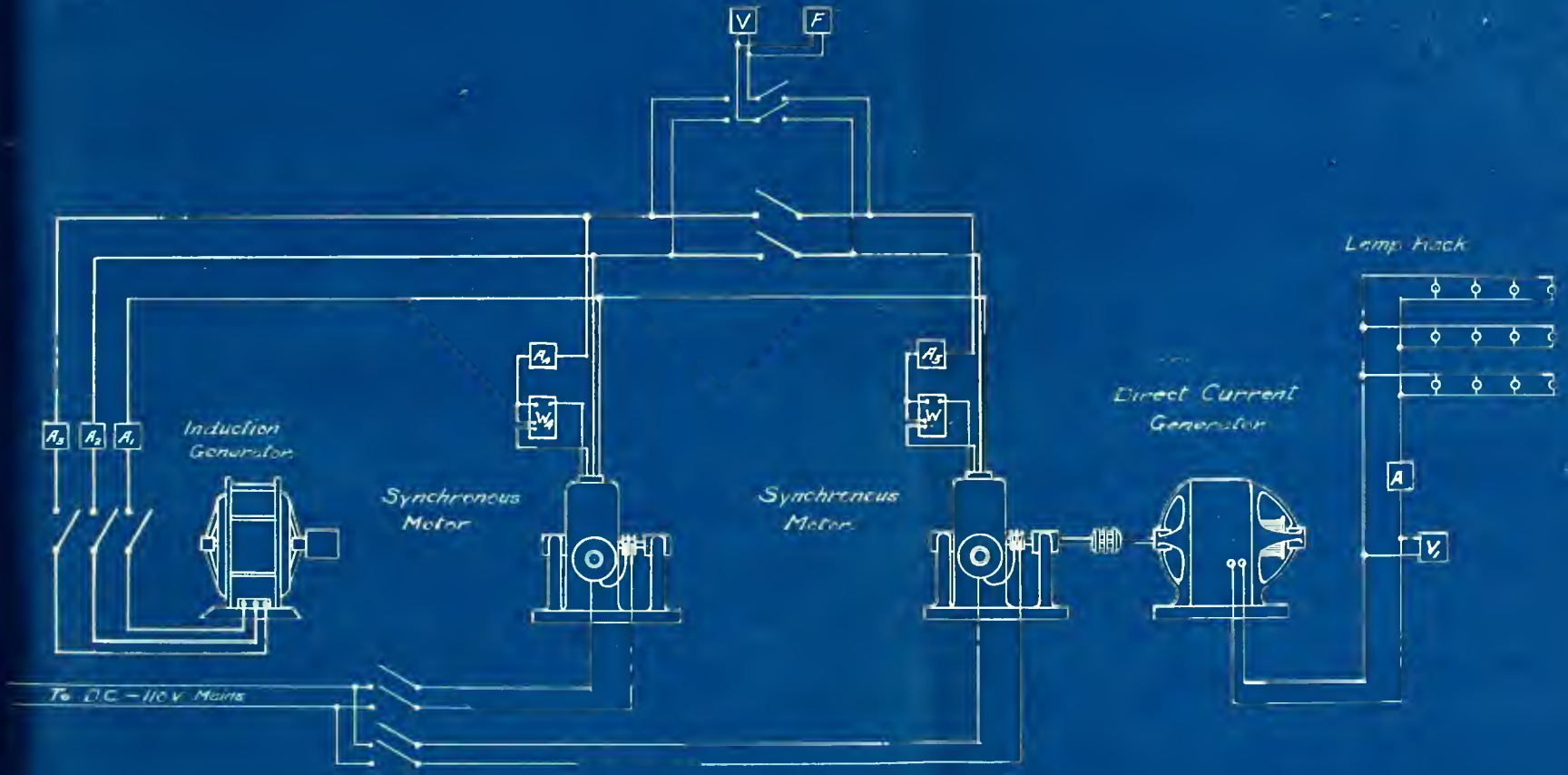
V
F
A3
A2
A1
Induction Generator
A4
W
Synchronous Motor
A5
W
Synchronous Motor
Direct Current Generator
Lamp Rack
A
V1
To D.C. — 110 v. Mains

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DIAGRAM of CONNECTIONS FOR ROTOR SPEED INDICATOR

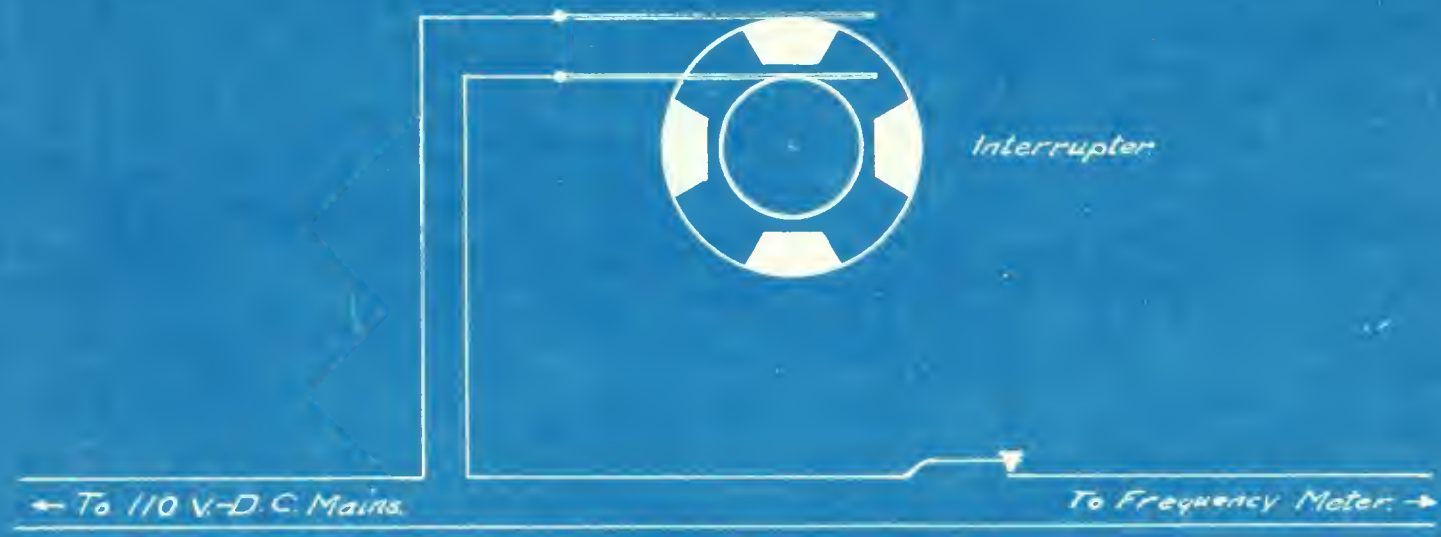

PLATE III.

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OUTLINE of CALCULATIONS

OUTLINE of CALCULATION

The passage from the experimental data to the desired results requires several calculations and a few assumptions, so that in order to make our results more intelligible the method of calculation will be outlined as briefly as possible.

All of our calculations are based on equivalent single phase quantities. By way of definition it would be well to state that by equivalent single phase current is meant, that value of current which when multiplied by the voltage across phases will give the apparent power in the system. In the case of a three phase balanced circuit, whether star or delta connected, the equivalent single phase current is equal to the square root of three, times the current in one phase line, as the apparent power in either case is equal to the voltage across phase lines times the square root of three times the line current. The equivalent single phase resistance is the value of resistance which when multiplied by the square of the equivalent single phase current will give the actual copper loss in the circuit. In three phase systems it may be shown that the equivalent single phase resistance is equal to one half of the resistance between phase lines as measured by D.C. instruments.

For the sake of clearness the calculations for each run may be classed under two general heads; the first those in which the data pertaining to the synchronous exciter is involved, and the second in which the data pertaining exclusively

to the induction generator is involved. From the wattmeter, voltmeter, and ammeter indications the apparent power and power factor of the synchronous exciter circuit were obtained. From the power factor the inductance factor was obtained and from the product of the equivalent single phase current and the inductance factor the wattless or exciting current is obtained. As all of the wattless current is furnished by the synchronous exciter, the system or generator inductance factor can be obtained from the from the ratio of the wattless current to the equivalent single phase current at the generator. This ratio being equal to the sine of the angle of lead of the system current, over the system E.M.F. Having obtained the generator inductance factor, and consequently the power factor, the stator wattless and power current may be calculated, and the current locus or circle diagram plotted.

The current locus of an induction machine consists of a curve plotted between the wattless and power components of the current . We found, as has been experimentally proven by several investigators, that the current locus closely approximates the arc of a circle, hence the name circle diagram. To illustrate the use made of the current locus we will refer to the locus plotted from the data obtained in run #2.

As this diagram is plotted between wattless and power components of the current, a line connecting the zero point

with any point P on the diagram will represent vectorially the stator current both as to direction and value. At no load, as a motor, there is no power given to the rotor, hence the rotor current at this point is practically zero. This point is shown on the diagram at A. As the change in the two components of the stator current is due to corresponding changes of the rotor current, it follows that the change of these components is a measure of the change of rotor current. Hence if we draw a line joining A and P we are completing a triangle, two sides of which represent the changes in the stator current, so that the closing side AP will represent the resultant producing this change, or, the rotor current, as referred to the stator. We could proceed further and obtain graphically several other quantities, but as the experimental data is a more accurate measure of these quantities, the experimental results are used, and the circle diagram is only used in determining the rotor current.

SAMPLE CALCULATION

Run #2 Item 2.

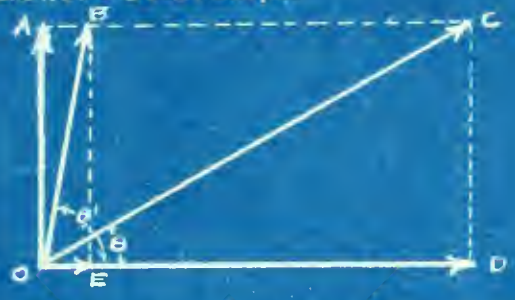
Synchronous Motor-

Line Current = 18 amps. Equiv. Single Phase $I = 18 \times \sqrt{3} = 31.2$ amps.
Power per phase = .331 KW. Total Power = $3 \times .33 = .99$ KW.
Voltage across phases = 200
Apparent power = $\sqrt{3}\,EI = 200 \times 31.2 = 6.275$ K.W.
Power factor: $.99 / 6.275 = .1578 = \cos \theta$

Inductance factor = $\sin \theta = .9875$
Wattless I = $.9875 \times 31.2 = 30.81$ amps.

Induction Generator

Determination of power factor.
Line Currents = 20.1, 20.1, 20.75 Equiv. Single Phase $I = \frac{20.1 + 20.1 + 20.75}{\sqrt{3}} = 35.$
Wattless I from exciter = 30.81 amps.



In above vector diagram,-
OB = Exciter I OA = Wattless component exciter I OE = Power component
E.D = Non-inductive load I OC = Generator I supplying exciter and non-inductive load. $\cos \theta_1$ = exciter. P.F.
Cos. θ = generator p.f = ?
$\frac{OA}{OC} = \sin \theta$ = inductance factor.
OA = 30.81 amps OC = 35.2 amps. $\sin \theta = \frac{30.81}{35.2} = .875 =$ i.f.
$\therefore$ P.F = .484.

Power I (stator) = $35.2 \times .484 = 17.02$ amps.
From current locus rotor I = 21.2 amps.

Stator resistance by D.C. method = .13786 Ω $\frac{.13786}{2}$ = Equivalent Single Phase R = .0689

Determination of rotor resistance
Total power stationary rotor = 1640 watts.
Equiv. S.P.I = 108.4
Stator copper loss = $(108.4)^2 \times .06893 = 809.5$ watts. $1640 - 809.5 = 830.5$ watts rotor copper l
$\frac{830.5}{(108.4)^2} = .0707\ \Omega$ rotor resistance referred to primary.

Power output = Power I x E = $17.02 \times 201 = 3405$ watts.
Stator copper loss = $(35.2)^2 \times .06893 = 85.05$ watts.
Determination of fixed losses
No load input as a motor = 840 watts.
" " current = " " " = 30.35 E.S.P. amps.
" " copper loss = $(30.35)^2 \times .06893 = 64$ watts.
$840 - 64 = 776$ = fixed losses.
Total stator loss = fixed losses + copper loss = $776 + 85.05 = 861.05$
Power output + stator losses = secondary power = $3405 + 861.05 = 4266.05$ watts.

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Rotor torque lbs.ft = $\frac{7.04 W_R}{S} = \frac{7.04 \times 4266}{1200} = 25.1$ #/'

W_R = rotor power = 4266 watts.
S = synchronous speed = 1200 r.p.m.

Rotor copper loss = $I_R^2 R = (21.2)^2 \times .0707 = 31.6$ watts
Watts imput = Rotor power + rotor copper loss = 31.6 + 4266 = 4297.6 watts

Efficiency = $\frac{\text{Output}}{\text{Imput}} = \frac{\text{Output}}{\text{Output + fixed loss + copper losses}} = \frac{3165}{4297.6} = 74.3\ \%$

Slip.
System frequency = 119 alternations per sec.
Generator " = 120 " " " corresponding to 1200 r.p.m of rotor

$\%\text{slip} = \frac{119 - 120}{119} \times 100 = -.84\ \%$

Regulation
No load voltage from magnetization curve = 206.2
Load voltage = 200
Regulation % = $\frac{206.2 - 200}{200} \times 100 = 3.1\ \%$

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MISCELLANEOUS DATA

Stator Resistance E.S.P = .06893 ohms

Rotor Resistance Determination.—

Total power stationary rotor = 1640 watts. E.S.P I_s = 108.4 amps.

Stator copper loss = $(108.4)^2 \times .06893$ = 809.6 watts.

Rotor copper loss = 1640 - 809.6 = 830.5 watts.

Rotor resistance = $\frac{830.5}{(108.4)^2}$ = .0707 ohms.

No Load Data as Motor.

Run No.	Power Input.	Apparent Power	E.S.P. Amps.	Power Factor	Inductance Factor	Wattless Amps.	Power Amps.	Fixed Losses.
2	840	6090	30.55	.138	.99	30.02	4.186	776.
4	300	1132	18.5	.265	.964	17.5	4.83	277.
5	240	2160	19.9	.1116	.994	19.28	2.22	213.

From Generator Name Plate

#174200 Type KT 6-25-1200 R.P.M.

Form 8 Cycles 60

H.P. 25 Speed 1200

Amps 62.5 Volts 220

GENERAL ELECTRIC Co.

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RUN #1 M A G N E T I Z A T I O N

C H A R A C T E R I S T I C S

RUN No 1.

MAGNETIZATION DATA.

Freq. of Circuit	E	I_4	Equiv. Single Phase Current	Power per Phase	Total Power	Apparent Power	Power Factor	Inductance Factor	Wattless Current	Power Current
Cycles	Volts	Amps.	Amps.	K.W.	K.W.	K.V.A.	cos. θ	sin. θ	Amps.	Amps.
60 Cycles.	98.2	8.6	14.88	.145	.435	1.46	.298	.9546	14.2	4.43
	108.2	9.3	16.1	.15	.45	1.742	.258	.9662	15.52	4.145
	120.	10.25	17.73	.175	.525	2.128	.2467	.9691	17.2	4.38
	128.8	11.	19.04	.185	.555	2.453	.2262	.9741	18.52	4.31
	139.	11.8	20.04	.205	.615	2.84	.2168	.9762	19.92	443
	149.	12.75	22.05	.225	.675	3.285	.2055	.9787	21.6	4.535.
	160	13.7	23.7	.25	.75	3.79	.1978	.9803	23.24	4.69
	169.2	14.7	25.42	.275	.825	4.305	.1915	.9815	24.95	4.87
	180.5	15.8	27.33	.295	.885	4.93	.1795	.9838	26.95	4.91
	190.	16.65	28.8	.305	.915	5.47	.1672	.9859	28.4	4.815
	201.3	17.4	30.6	.350	1.05	6.165	.1705	.9854	30.15	5.22
	212.	18.4	31.82	.375	1.125	6.75	.1667	.9860	31.4	5.3
	221.	19.4	33.55	.40	1.2	7.415	.1618	.9868	33.15	5.43
	234.	20.4	35.3	.465	1.395	8.265	.1688	.9857	34.75	5.96
	238.7	21.	36.33	.485	1.455	8.68	.1676	.9859	35.82	6.085
50 Cycles.	87.	9.	15.57	.1	.3	1.354	.2215	.9766	15.2	3.45
	96.	10.	17.33	.125	.375	1.66	.2259	.9742	16.84	3.91
	108.5	11.3	19.55	.145	.435	2.122	.2048	.9788	19.14	4.
	119.	12.2	21.10	.15	.45	2.51	.1792	.9838	20.77	3.785
	130.	13.5	23.35	.165	.495	3.035	.1630	.9866	23.06	3.805
	139.	14.5	25.1	.185	.555	3.485	.1592	.9872	24.72	3.995
	149.	15.6	27.	.2	.6	4.02	.1493	.9888	26.66	4.03
	156.7	16.4	28.35	.235	.705	4.445	.1585	.9874	28.05	4.5
	169.	17.7	30.6	.265	.795	5.175	.1535	.9881	30.26	4.705
	189.5	20.5	35.45	.325	.975	6.72	.145	.9894	35.12	5.14

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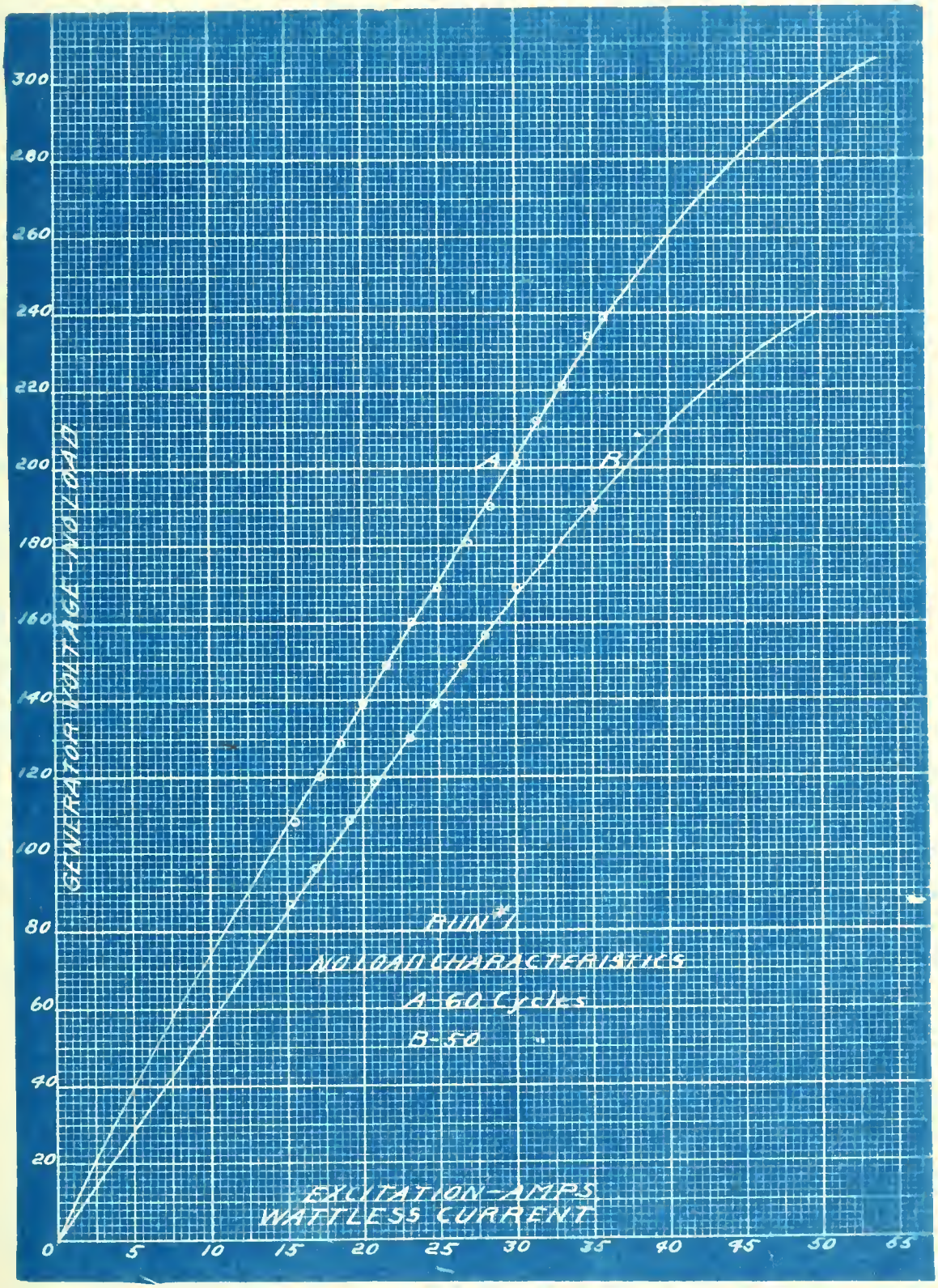
GENERATOR VOLTAGE-NO LOAD
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
5
10
15
20
25
30
35
40
45
50
55
A
B
RUN #1
NO LOAD CHARACTERISTICS
A-60 Cycles
B-50 "
EXCITATION-AMPS
WATTLESS CURRENT

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SUMMARY OF RESULTS.

In the case of the induction generator the magnetization characteristic is plotted between wattless current and the no load voltage. As in the case of the synchronous machine the increase in voltage is directly proportional to the increase in excitation, until the point of saturation is reached. At this point there is a bend or knee in the curve. In the characteristics obtained experimentally the knee is not very pronounced as we were unable to carry the curve above 230 volts owing to the fact that our exciter was a 110 volt machine. As was to be expected, the 50 cycle characteristic is similar to the 60 cycle characteristic, with the exception that the voltage for a given value of wattless current is much lower.

RUN #2 L O A D C H A R A C T E R I S T I C S

Voltage Constant at 200, Rotor. Speed constant

at 1200 R.P.M.

No load frequency 60 cycles.

RUN N°2.

CONSTANT ROTOR SPEED -200V-60~.

SYNCHRONOUS MOTOR								LAMP LOAD				INDUCTION GENERATOR																				
I_4	Equiv Single Phase Current	Power per Phase	Total Power	Apparent Power	Power Factor	Inductance Factor	Wattless Current	W_1	W_2	W_3	Total Power	I_1	I_2	I_3	Equiv Single Phase Current	Total Power	Inductance Factor	Power Factor	Rotor Current	Rotor Current	Stator Copper Loss	Total Stator Loss	Rotor Power	Rotor Copper Loss	Input	Output	Eff.	Frez's Circuit	Slip	Rotor Torque	No Load Voltage	Regulation
Amps.	Amps.	K.W.	K.W.	K.V.A.	cos θ	Sin θ	Amps.	K.W.	K.W.	K.W.	K.W.	Amps.	Amps.	Amps.	Amps.	K.W.	Sin θ	cos θ	Amps.	Amps.	Watts	Watts	Watts	Watts	Watts.	Watts.	%	Alternations	%	Lbs. Ft	Volts	%
17.5	30.3	.33	.99	6.1	.1623	.9868	30.	0	0	0	0	17.2	17.6	18.	30.55	.99	.352	.1.888	5.76	5.9	64.	840.	1992	6.9	1999	1152	57.8	119.5	.415	11.7	200.6	.4
18.	31.2	.33	.99	6.275	.1578	.9875	30.65	.67	.67	.63	1.97	20.1	20.1	20.75	35.2	2.96	.875	.484	11.02	21.2	85.1	961.1	4266	31.6	4298	3405	79.3	119.	.84	25.1	206.2	3.1
18.1	31.38	.30	.90	6.31	.1425	.9898	31.08	1.215	1.2	1.185	3.6	22.5	22.5	23.4	40.1	4.5	.786	.6182	24.41	28.9	113.7	936.7	5772	59.85	5831	4885	83.9	118.75	1.052	33.42	208.2	4.1
18.9	32.79	.30	.90	6.59	.1368	.9906	32.4	1.8	1.8	1.76	5.36	26.5	26.65	27.25	46.45	6.26	.698	.7161	33.22	37.6	148.	924.	7563	99.8	7662	6645	85.3	118.25	1.48	43.45	216.2	8.1
19.85	34.4	.29	.84	6.92	.1218	.9926	34.2	2.45	2.43	2.415	7.295	31.2	31.6	32.1	54.8	8.135	.624	.7814	42.8	47.	206.5	982.5	9543	155.8	9698	8560	89.45	118.	1.692	56.	226.4	13.2
21.15	36.6	.325	.975	7.37	.1323	.9912	36.3	3.02	3.02	2.97	9.01	35.75	35.75	35.75	62.05	9.985	.585	.8111	50.45	55.	265.	1041.	11121	203.5	11325	10080	88.95	117.75	1.912	64.95	240.	20.
21.75	37.6	.38	1.14	7.585	.1503	.9886	37.2	3.34	3.395	3.26	9.985	38.75	39.25	38.6	67.4	11.125	.553	.8331	56.1	60.8	312.	1088.	12308	260.	12568	11220	89.4	117.25	2.341	72.4	246.	23.
23.5	40.74	.23	.84	8.2	.1026	.9947	40.55	4.22	4.26	4.18	12.66	45.8	46.2	46.8	80.1	13.5	.505	.8631	69.2	74.4	441.	1217.	15037	389.	15446	13940	89.6	116.5	3.	88.3	260.	30.
25.15	43.5	.275	.825	8.76	.1248	.9923	43.24	4.91	4.935	4.67	14.415	51.5	51.2	52.1	88.5	15.24	.4835	.8753	78.4	83.5	550.5	1326.5	17007	490.2	17497	15680	89.6	115.5	3.9	99.9	273.	36.5
29.7	51.6	.25	.75	10.34	.0725	.9974	51.32	6.07	6.07	5.83	17.47	63.15	62.6	62.8	109.	18.72	.471	.8821	96.65	102.8	818.	1594.	20794	740.	21534	19200	89.25	114.5	4.81	121.8	301.	50.5
31.0	53.5	.25	.75	10.77	.0696	.9976	53.45	6.575	6.525	6.35	19.45	68.25	66.6	67.9	117.2	20.2	.455	.8905	104.2	111.2	949.	1725.	22555	882.	23407	20830	89.	113.5	5.735	138.	324.2	58.1

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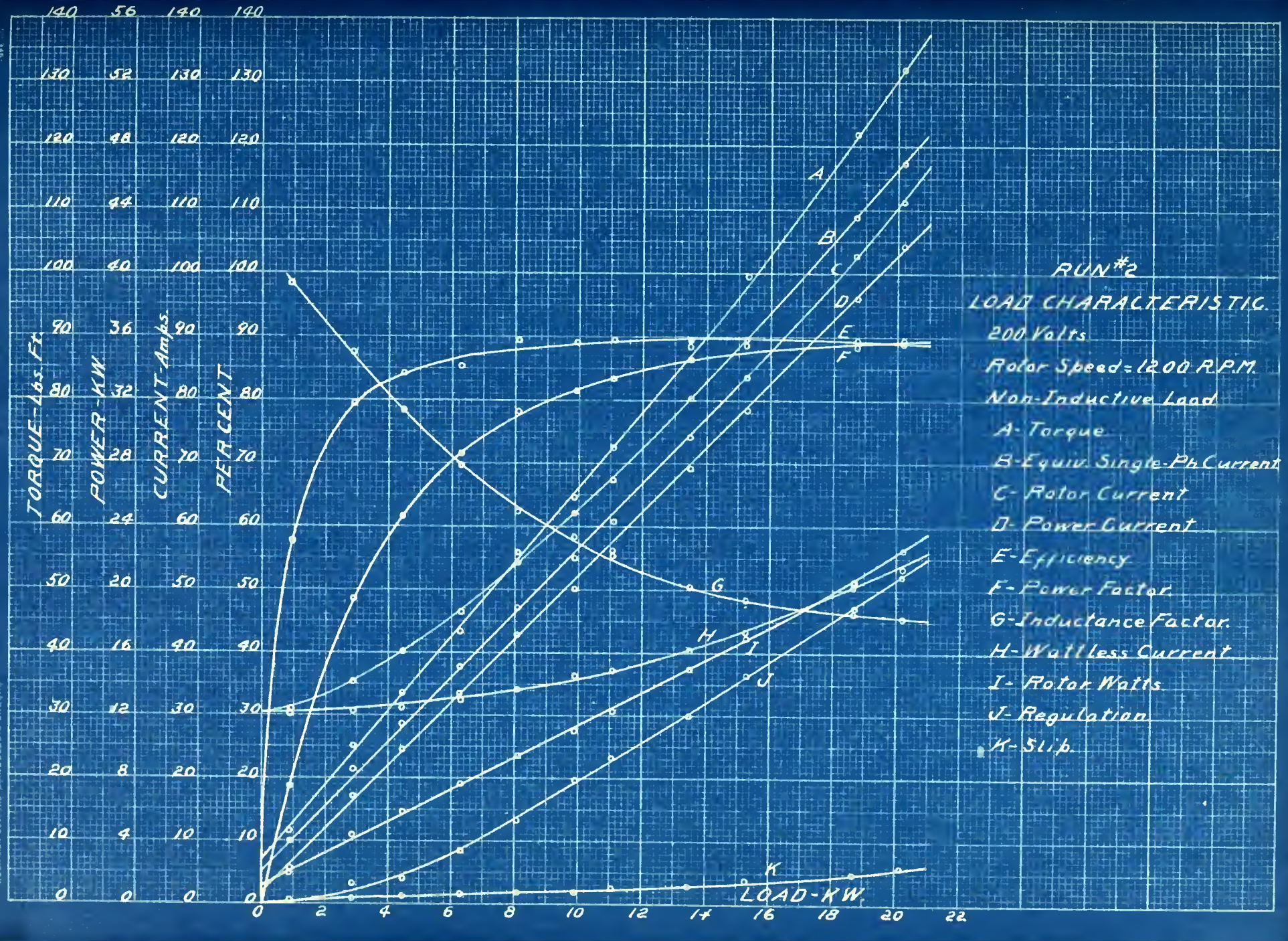
RUN #2
LOAD CHARACTERISTIC.
200 Volts
Rotor Speed = 1200 R.P.M.
Non-Inductive Load
A- Torque.
B- Equiv. Single-Ph Current
C- Rotor Current
D- Power Current
E- Efficiency
F- Power Factor.
G- Inductance Factor.
H- Wattless Current.
I- Rotor Watts.
J- Regulation.
K- Slip.
TORQUE-Lbs. Ft.
POWER-KW
CURRENT-Amps.
PER CENT
LOAD-KW.
0 2 4 6 8 10 12 14 16 18 20 22
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140

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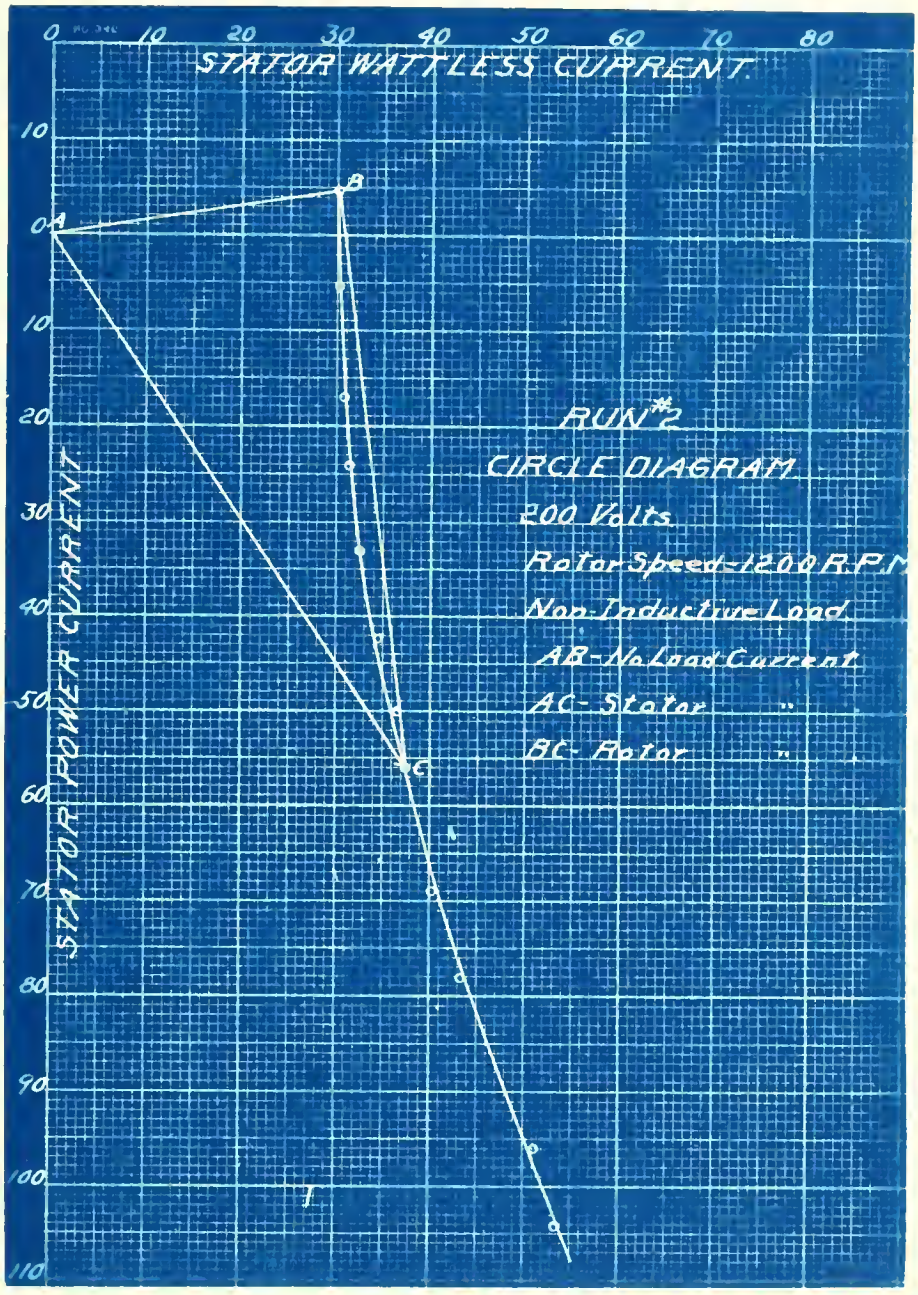
STATOR WATTLESS CURRENT.
0
10
20
30
40
50
60
70
80
STATOR POWER CURRENT.
A
B
C
RUN #2
CIRCLE DIAGRAM
200 Volts
Rotor Speed-1200 R.P.M
Non-Inductive Load.
AB-No Load Current
AC- Stator "
BC- Rotor "

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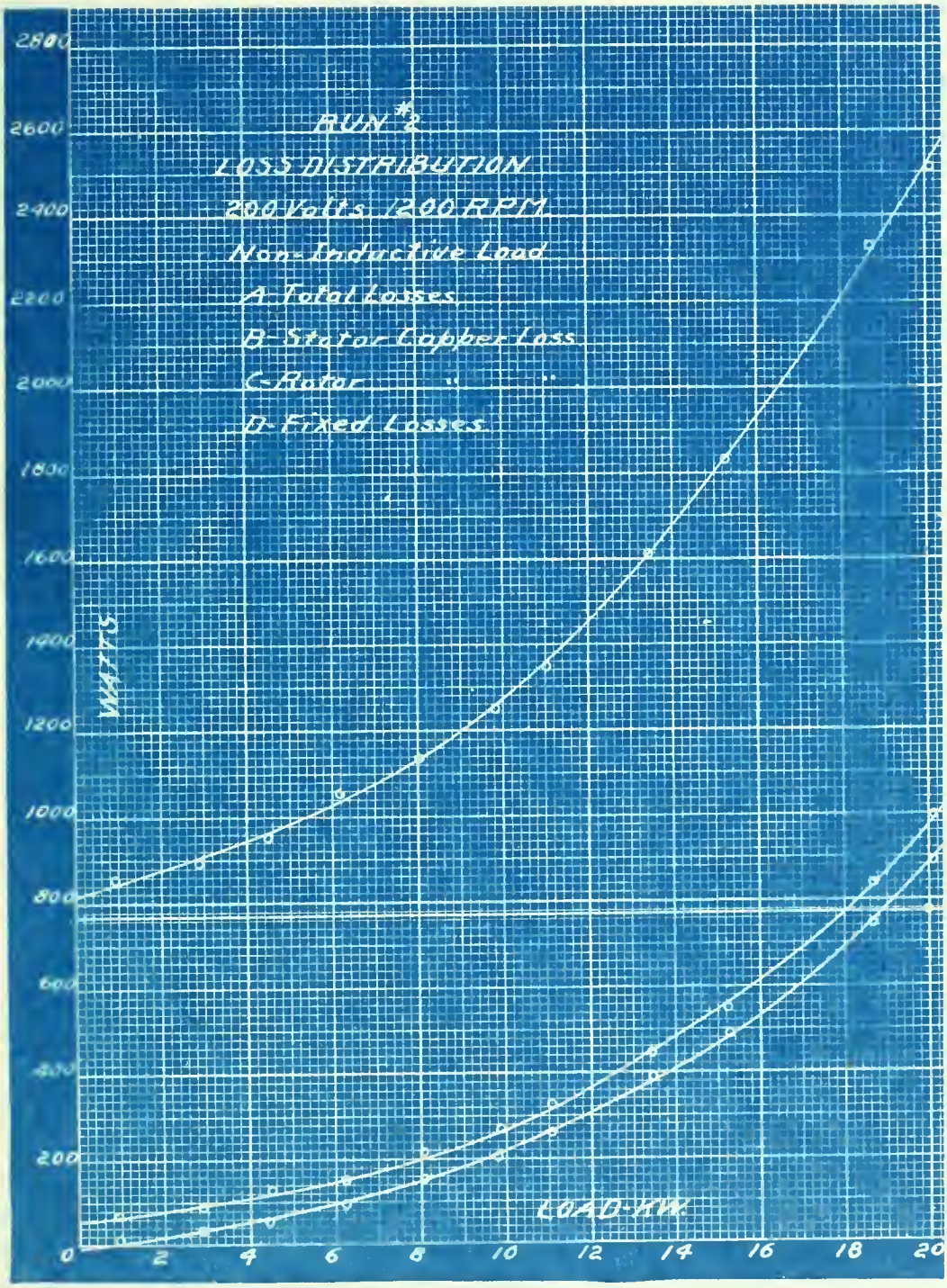
RUN #2
LOSS DISTRIBUTION
200 Volts 1200 R.P.M.
Non-Inductive Load
A-Total Losses
B-Stator Copper Loss
C-Rotor " "
D-Fixed Losses
WATTS
LOAD-KW
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
2
4
6
8
10
12
14
16
18
20

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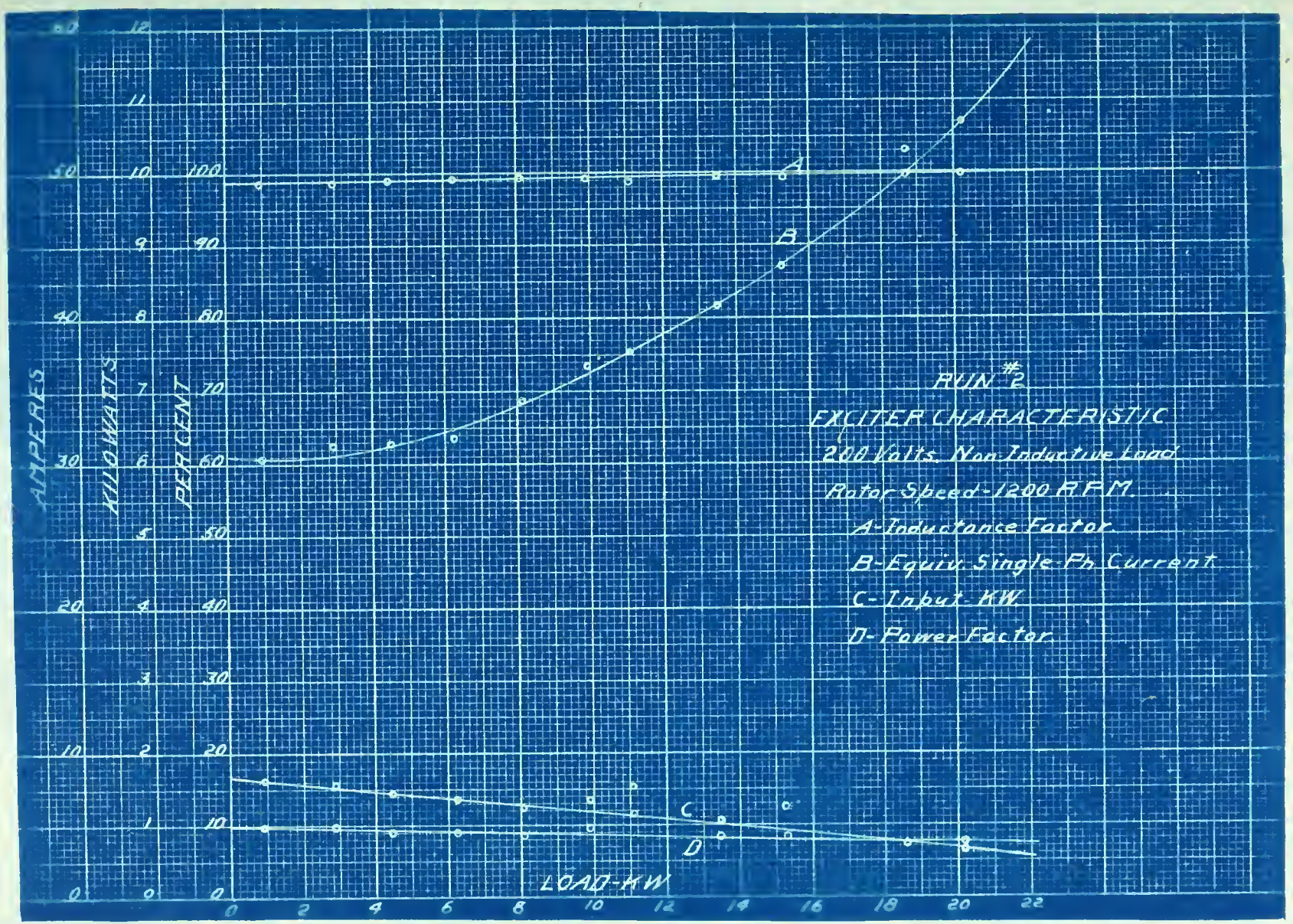
AMPERES
KILOWATTS
PER CENT
LOAD-KW
A
B
C
D
RUN #2
EXCITER CHARACTERISTIC
200 Volts. Non Inductive Load
Rotor Speed-1200 R.P.M.
A-Inductance Factor
B-Equiv. Single Ph. Current
C-Input KW
D-Power Factor

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SUMMARY OF RESULTS.

The results obtained in this run can best be discussed from an inspection of the adjacent curve sheet. The most important characteristic is the generator efficiency, which is in the neighborhood of ninety percent for all loads above half load. This is a remarkably high efficiency for a machine of this size, and compares favorable with synchronous generators of like size.

Another important characteristic is that of the power factor, which varies greatly with load. This variation of power emphasizes the fact that the induction generator has no definite power factor and that its power factor depends entirely upon that of the load. Because of this characteristic of the induction generator, the power factor rises rapidly with the increase of non-inductive load, reaching a maximum value of eighty nine percent. The relations of the various currents and their components are among the characteristics shown. The equivalent single phase or stator current is not proportional to the load owing to the variation of its components. Of these the power component is directly proportional to the load as this component represents the actual power given to the load. The wattless component is the exciting current, and increases slightly with load. This increase is necessary to maintain the pressure at a constant value. The regulation of the induction generator does not compare favorably

with the synchronous generator, as our results give the regulation at full load as more than fifty per cent. However poor regulation in the induction generator does not mean as much as in the case of the synchronous generator, inasmuch as the induction generator is excited by wattless current and a very little additional power is required to maintain the voltage as the load increases. Theoretically it would seem, as the excitation is wattless current, that there would be no power current required and hence no expenditure of power. Our experimental data shows that when the excitation is obtained from an unloaded synchronous motor, there is an increase in the power component of the exciting current as the load is increased. This is probably due to the fact that in order to furnish the additional wattless current required by an increase in load, the fields of the synchronous motor must be strengthened, which would tend to increase the power required to drive the motor and hence require a larger power current from the generator.

The rotor current is found to differ from the stator current by a quantity which is not constant, but it is also found to differ from the power component of the stator current by an almost constant quantity. This would indicate that could we measure the power factor of the rotor it would be found to differ from that of the stator and would be nearer unity.

RUN #3 L O A D C H A R A C T E R I S T I C S.

Voltage constant at 200, Frequency

Constant at 60 cycles.

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RUN N°3.

CONSTANT FREQUENCY - 200 V - 60 ~

SYNCHRONOUS MOTOR.								LAMP LOAD.				INDUCTION GENERATOR.																					
I_4	Equiv. Single-Phase Current	Power per Phase.	Total Power.	Apparent Power.	Power Factor	Inductance Factor	Wattless Current	W_1	W_2	W_3	Total Power.	I_1	I_2	I_3	Equiv. Single-Phase Current.	Total Power.	Inductance Factor.	Power Factor.	Power Current.	Rotor Current.	Stator Copper Loss.	Total Stator Loss.	Rotor Power	Rotor Copper Loss.	Input	Output	Eff.	Free. of Speed Indicator	Speed of Rotor.	Slip.	Rotor Torque.	No Load Voltage	Regulation.
Amps.	Amps.	K.W.	K.W.	K.V.A.	cos. θ	sin. θ	Amps.	K.W.	K.W.	K.W.	K.W.	Amps.	Amps.	Amps.	Amps.	K.W.	sin. θ	cos. θ	Amps.	Amps	Watts	Watts	Watts	Watts	Watts	Watts	°/o	Alternations.	R.P.M.	°/o	Lbs. Ft.	Volts	°/o
17.6	30.45	.33	.99	6.125	.1614	.9869	30.13	0	0	0	0	17.9	18.1	17.1	30.67	.99	.932	.1888	5.8	10.	648	840.8	2006.8	7.07	2013.87	1166.	57.8	81.	1215	1.25	11.77	202.5	.746
18.	31.15	.34	1.02	6.265	.1628	.9867	30.8	.67	.67	.65	1.99	19.8	20.	19.25	34.13	3.01	.9025	.4308	15.09	19.25	80.3	836.3	3839.3	26.2	3917.5	3035	77.5	81.	1215	1.25	22.85	208.7	2.835
18.7	32.35	.275	.825	6.51	.1267	.9919	32.13	1.35	1.34	1.3	3.99	23.7	22.75	22.75	40.	4.815	.803	.596	23.83	28.1	110.3	886.3	5676.3	55.75	5732.	4790.	83.6	81.5	1223	1.9175	33.32	214.8	6.86
19.	32.85	.25	.75	6.61	.1134	.9935	32.7	1.88	1.83	1.78	5.49	27.25	26.3	26.7	46.35	6.24	.705	.7092	32.9	37.2	148.1	924.3	7544.3	97.75	7642.	6620.	86.6	81.5	1223	1.9175	44.25	218.5	8.7
19.5	33.75	.34	1.02	6.785	.1504	.9886	33.4	2.275	3.25	2.225	7.75	29.75	30.1	29.1	51.4	8.77	.65	.7599	33.1	43.1	182.3	958.3	8823.3	131.2	8954.5	7865.	87.8	82.	1230	2.5	51.75	222.5	10.7
20.7	35.63	.28	.84	7.2	.1167	.9932	35.67	2.92	2.91	2.85	8.68	34.6	34.75	34.4	60.	9.52	.5945	.8041	48.3	52.7	248.	1024.	10744.	196.2	10940.	9720.	88.8	82.	1230	2.5	63.1	236.	17.4
21.9	37.9	.25	.75	7.62	.0984	.9951	37.8	3.625	3.875	3.5	11.	40.25	39.75	40.1	69.4	11.75	.544	.8391	59.	63.7	332	1108.	12958.	285.5	13243.5	11860.	89.4	82.5	1238	3.165	76.1	248.	23.4
23.25	40.2	.2	.6	8.1	.074	.9973	40.2	4.26	4.22	4.12	12.6	46.	44.9	46.5	79.5	13.2	.508	.8625	68.5	73.6	435	1211.	14981.	382.5	15363.5	13770.	89.5	83.	1245	3.75	87.9	261.	29.85
25.15	43.5	.175	.525	8.76	.0599	.9982	43.5	5.05	5.01	4.9	14.96	52.	51.25	53.	90.3	15.485	.482	.8762	79.15	84.5	562	1338.	17258.	504.	17762.	15920.	89.6	83.25	1250	4.17	101.3	276.5	37.1
26.8	46.35	.125	.375	9.33	.0402	.9992	46.4	5.72	5.57	5.4	16.69	58.1	56.9	58.5	100.25	17.065	.463	.8863	88.9	94.5	632	1468.	19343.	633.	19976.	17876.	89.5	83.75	1255	4.58	113.5	287.	42.75
29.65	49.6	.07	.21	10.32	.02035	.9998	51.35	6.5	6.3	6.025	18.825	65.1	62.5	67.5	112.75	19.035	.4555	.8902	100.3	107.	877	1653.	21803.	809.	22612.	20150.	89.1	84.	1260	5.	128.	301.	49.7

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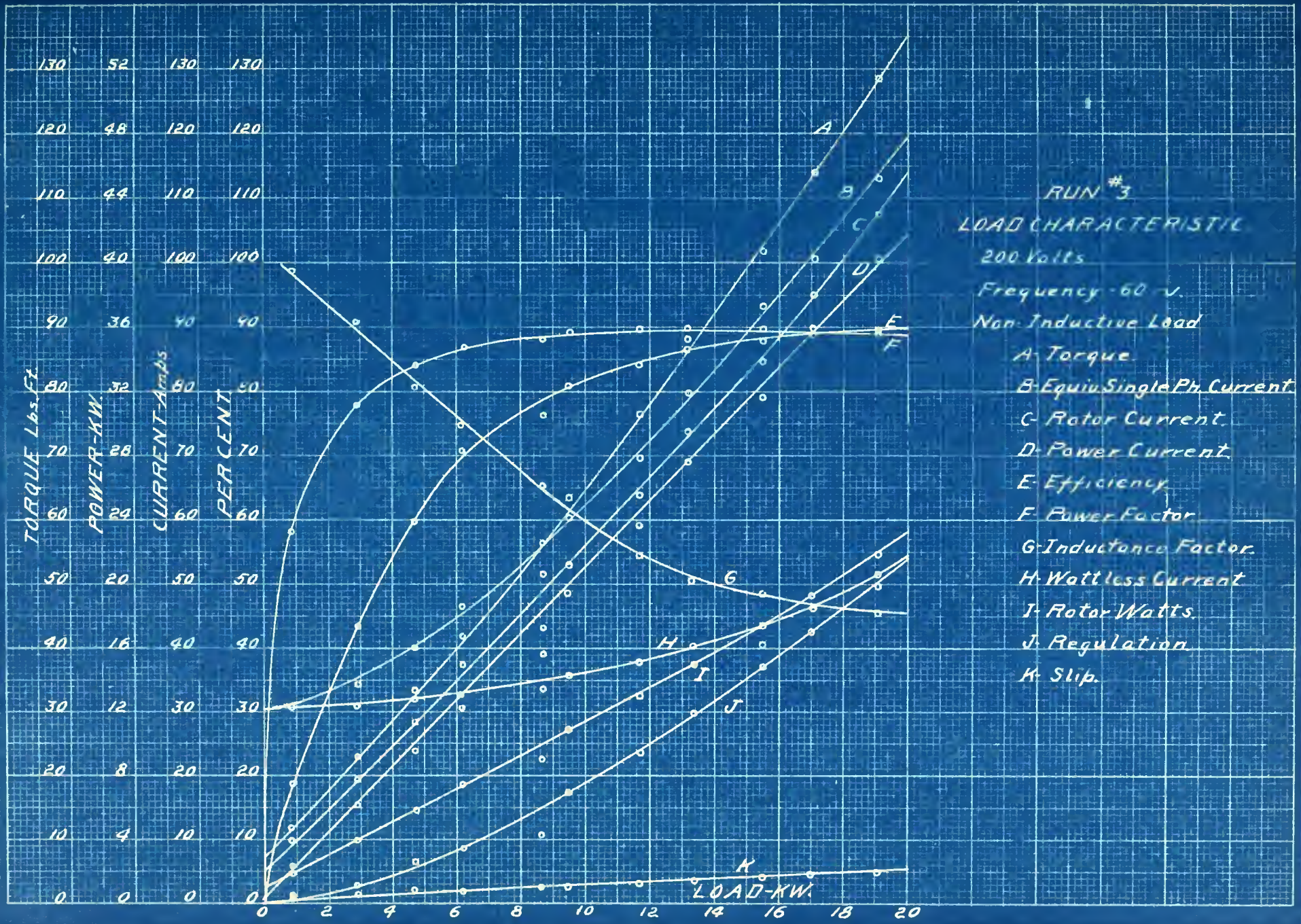
TORQUE Lbs.-Ft.
POWER-KW.
CURRENT-Amps.
PER CENT
LOAD-KW.
0
2
4
6
8
10
12
14
16
18
20
A
B
C
D
E
F
G
H
I
J
K
RUN #3
LOAD CHARACTERISTIC
200 Volts
Frequency - 60 ~
Non-Inductive Load
A- Torque.
B- Equiv. Single Ph. Current.
C- Rotor Current.
D- Power Current.
E- Efficiency.
F- Power Factor.
G- Inductance Factor.
H- Wattless Current.
I- Rotor Watts.
J- Regulation.
K- Slip.

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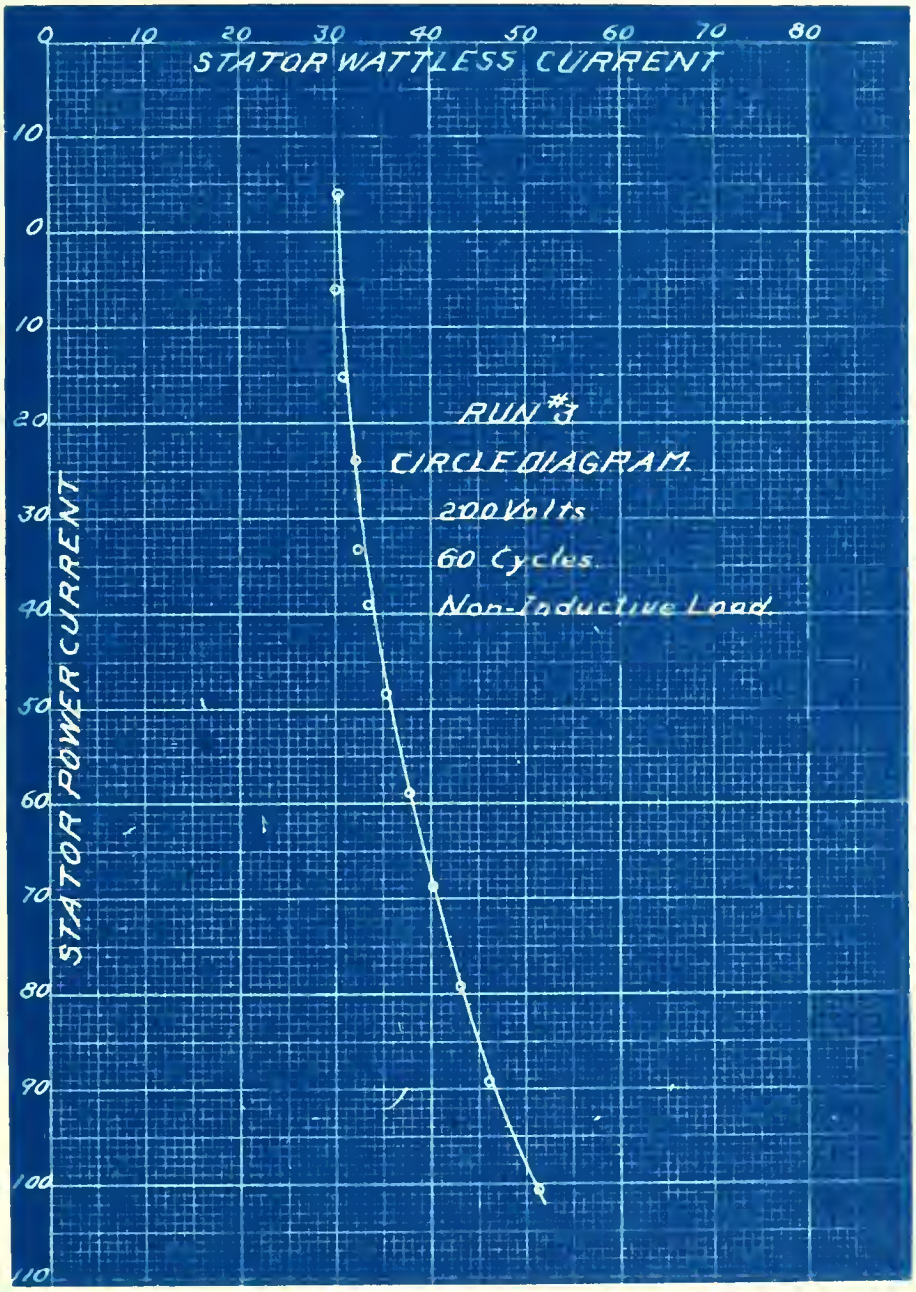
0
10
20
30
40
50
60
70
80
STATOR WATTLESS CURRENT
10
0
10
20
30
40
50
60
70
80
90
100
110
STATOR POWER CURRENT
RUN #3
CIRCLE DIAGRAM.
200 Volts
60 Cycles.
Non-Inductive Load.

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SUMMARY OF RESULTS.

The characteristics obtained in this run are almost identical with those of Run #2. This would indicate that the same results are to be obtained whether the induction generator is operated with constant rotor speed or whether the rotor speed is increased to keep the circuit frequency constant. Of course, it is a question whether the speed of the prime mover must be kept constant, or whether the nature of the load is such that the frequency must be kept constant.

RUN #4. L O A D C H A R A C T E R I S T I C S

Voltage Constant at 110. Rotor Speed Constant at 1200 R.P.M.

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RUN No 4

CONSTANT ROTOR SPEED - 110 V. - 60 ~

SYNCHRONOUS MOTOR.								LAMP LOAD				INDUCTION GENERATOR.																					
I_4	Equiv. Single Phase Current	Power per Phase.	Total Power	Apparent Power	Power Factor	Induct-ance Factor.	Wattless Current	W_1	W_2	W_3	Total Power.	I_1	I_2	I_3	Equiv. Single-Phase Current	Total Power	Induct-ance Factor.	Power Factor.	Power Current	Rotor Current	Stator Copper Loss	Total Stator Loss.	Rotor Power.	Rotor Copper Loss.	Input.	Output.	Eff.	Freq. of Circuit.	Slip.	Rotor Torque.	No Load Voltage	Regulation
Amps.	Amps.	K.W.	K.W.	K.V.A	cos. θ	sin. θ	Amps.	K.W.	K.W.	K.W.	K.W.	Amps.	Amps.	Amps.	Amps.	K.W.	sin. θ	cos. θ	Amps.	Amps.	Watts	Watts	Watts	Watts	Watts	Watts	%	Alter-nations.	%	Lbs. Ft.	Volts	%
9.75	16.87	.15	.45	1.825	.2465	.9691	16.34	0	0	0	0	10.1	10.1	10.5	17.75	.45	.923	.3848	4.525	9.2	21.65	300	788	6.	794	488	61.65	119.	.84	4.56	116.2	8.25
11.	19.03	.09	.27	2.06	.131	.9914	18.87	.67	.66	.57	1.9	16.5	15.	16.5	27.79	2.17	.682	.7314	23.89	28.15	53.	330	2910.	56.	2966	2580	87.	117.	2.56	17.05	130.	20.42
11.5	19.9	.1	.3	2.155	.1392	.9903	19.7	.915	.9	.83	2.645	19.5	18.5	20.1	33.6	2.945	.588	.8098	27.19	32.1	77.6	3546	3283.6	72.8	3360	2935	87.3	116.75	2.79	19.28	136.	25.85
12.75	22.06	.09	.27	2.386	.1132	.9936	21.9	1.255	1.255	1.21	3.72	24.6	23.8	25.2	42.6	3.99	.517	.856	36.91	41.8	125.	402.	4341.	124.	4465	3939	88.1	116.75	3.22	25.42	151.2	40.
13.9	24.05	.1	.3	2.605	.1151	.9934	23.95	1.5	1.5	1.485	4.485	29.15	29.	30.	51.	4.785	.47	.8827	45.	50.	179.	456.	5311.	176.1	5487	4955	88.55	116.	3.45	31.18	163.2	51.1
15.5	26.8	.125	.375	2.905	.129	.9916	26.6	1.785	1.785	1.75	5.32	34.2	34.2	34.6	59.5	5.675	.4475	.8943	53.18	58.8	244.	521.	6266.	244.8	6511	5745	88.3	115.75	3.658	36.19	180.1	66.75
17.8	30.8	.125	.375	3.333	.1125	.9936	30.55	2.13	2.16	2.115	6.405	39.75	39.25	40.	68.8	6.78	.445	.895	61.25	67.8	325.	602.	7220.	325.	7545	6618	87.95	115.25	4.12	42.4	206.	90.31
20.15	34.85	.150	.45	3.775	.1192	.9929	34.55	2.51	2.5	2.47	7.48	46.5	46.5	46.5	80.55	7.93	.429	.9032	72.65	79.8	446.5	723.	8572.5	450.	90225	7849	87.	114.5	4.801	50.3	229.	102.8
21.85	37.8	.165	.495	4.09	.121	.9927	37.55	2.65	2.65	2.605	7.905	50.5	50.	49.4	86.55	8.4	.4345	.9007	78.	85.	515.5	792.5	9217.5	521.	97385	8425	86.5	113.	6.195	53.05	246.	126.9
24.65	42.65	.19	.57	4.615	.1235	.9923	42.3	3.03	2.99	2.94	8.96	56.	56.2	54.6	96.45	9.53	.44	.898	86.5	95.	639.5	916.5	10256.	638.5	108945	9340	85.8	112.5	6.775	60.2	272.	151.9
27.2	47.05	.2	.6	5.095	.1177	.993	46.7	3.15	3.2	3.16	9.51	60.	60.75	59.	103.9	10.11	.4505	.8927	92.51	102.	740.	1017.	11017	735.5	117525	10000	85.	111.5	7.625	64.6	288	167.
30.2	52.25	.225	.675	5.66	.1325	.9912	51.7	3.44	3.5	3.46	10.4	65.6	67.	64.5	114.	11.075	.455	.8905	101.8	112.	895.	1172.	12122	888.	13000.	10950	84.3	110.5	8.6	71.15	311	189.

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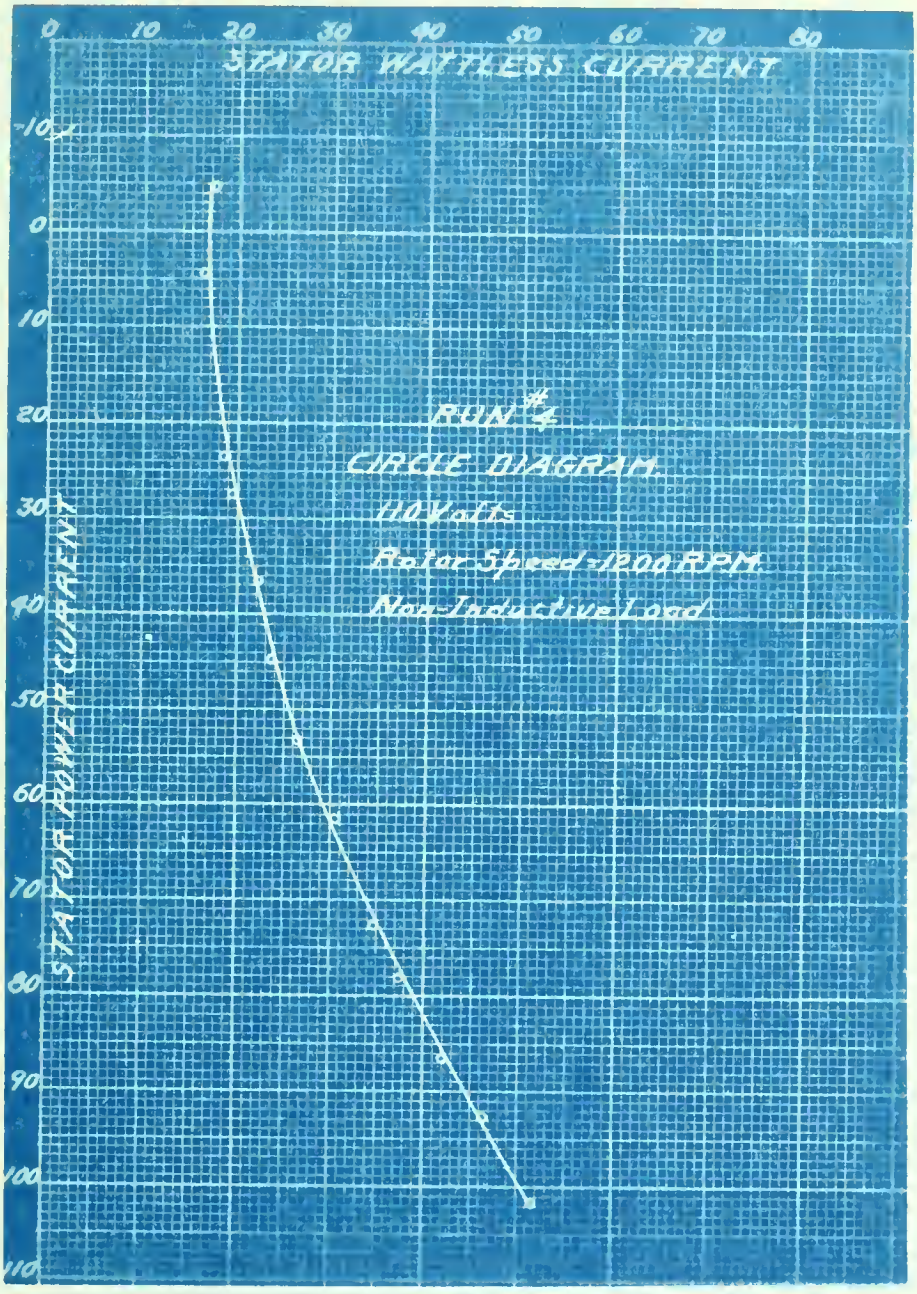
0
10
20
30
40
50
60
70
80
STATOR WATTLESS CURRENT
-10
0
10
20
30
40
50
60
70
80
90
100
110
STATOR POWER CURRENT
RUN #4
CIRCLE DIAGRAM.
110 Volts
Rotor Speed-1200 R.P.M.
Non-Inductive Load

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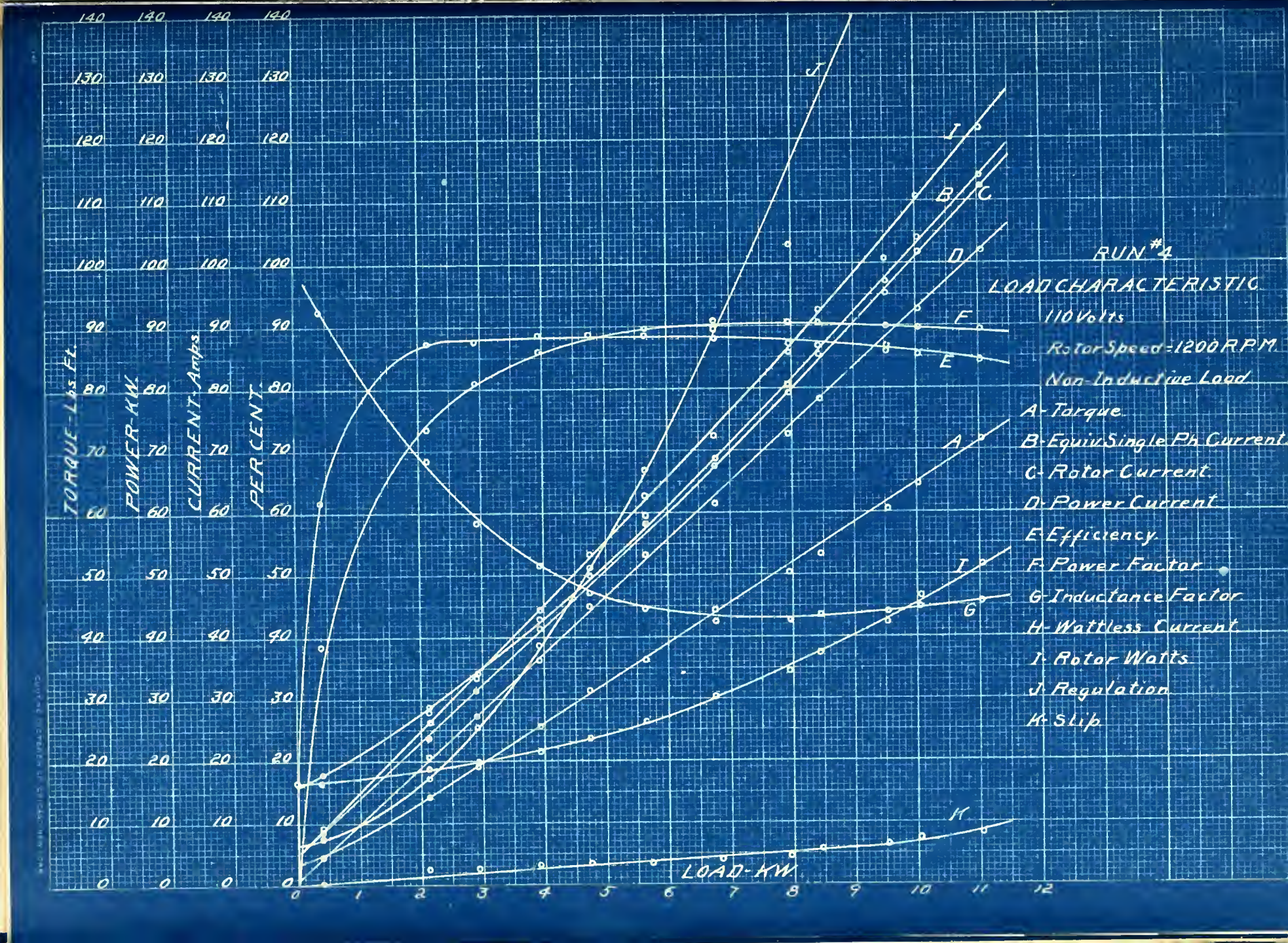
TORQUE-Lbs.Ft.
POWER-KW.
CURRENT-Amps.
PER CENT.
LOAD-KW.
RUN #4
LOAD CHARACTERISTIC
110 Volts
Rotor Speed = 1200 R.P.M.
Non-Inductive Load
A-Torque.
B-Equiv. Single Ph. Current.
C-Rotor Current.
D-Power Current.
E-Efficiency.
F-Power Factor.
G-Inductance Factor.
H-Wattless Current.
I-Rotor Watts.
J-Regulation.
K-Slip.

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SUMMARY OF RESULTS.

The main object of this run was to show the effect of operating the machine at a voltage less than the rated voltage. Our results show that the efficiency is only slightly less than that obtained at the higher voltage. The power factor is in general higher than at the higher voltage, particularly at the light loads. The remaining characteristics are practically the same as those obtained at 200 volts, with the exception that the regulation is extremely poor at the lower voltage. In general we may conclude from the results of this run that the important characteristics of the induction generator, namely the efficiency, power factor and induction factor, are independent of the voltage at which the machine is operated.

Run #5. L O A D C H A R A C T E R I S T I C S.

Voltage Constant at 110. Rotor Speed Constant at 1200 R.P.M.

No Load Frequency 50 cycles.

RUN #6. L O A D C H A R A C T E R I S T I C S

Voltage Constant at 200. Rotor Speed

Constant at 1200 R.P.M.

Synchronous Motor Load.

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EUGENE DIETZGEN CO., CHICAGO-NEW YORK

RUN Nº 5.

CONSTANT ROTOR SPEED – 110 V. – 50 ~

SYNCHRONOUS MOTOR.								LAMP LOAD.				INDUCTION GENERATOR.																				
I_4	Equiv. Single-Phase Current.	Power per Phase.	Total Power.	Apparent Power.	Power Factor.	Induct-ance Factor.	Wattless Current	W_1	W_2	W_3	Total Power.	I_1	I_2	I_3	Equiv. Single Phase Current.	Total Power.	Induct ance Factor.	Power Factor.	Power Current.	Rotor Current.	Stator Copper Loss.	Total Stator Loss.	Rotor Power.	Rotor Copper Loss.	Input.	Output.	Eff.	Freq. of Circuit.	Slip.	Rotor Torque	No Load Voltage	Reg-ulation
Amps.	Amps.	K.W.	K.W.	K.V.A.	Cos. θ	Sin. θ	Amps.	K.W.	K.W.	K.W.	K.W.	Amps.	Amps.	Amps.	Amps.	K.W.	Sin. θ.	Cos. θ	Amps.	Amps.	Watts.	Watts.	Watts.	Watts.	Watts.	Watts.	%	Alter-nations.	%	Lbs. Ft.	Volts.	%
11.5	19.9	.125	.375	2.148	.1745	.9847	19.63	0	0	0	0	12.	12.	11.65	20.6	.375	.953	.3029	6.24	7.6	29.25	242.	916.	4.08	920.1	674	67.4	99.25	.765	5.37	111.5	3.24
11.8	20.45	.12	.36	2.206	.1633	.9866	20.2	.37	.37	.37	1.11	14.52	14.1	13.6	24.4	1.47	.8275	.5615	13.73	16.	41.1	253.85	1736.85	18.1	1754.9	1483	84.5	98.75	1.266	10.2	114.5	6.02
12.5	21.65	.09	.27	2.335	.1155	.9933	21.53	.73	.73	.7	2.16	18.1	17.65	18.75	31.5	2.43	.6835	.73	23.	25.3	68.4	281.15	2766.15	45.3	2811.5	2485	88.4	98.	2.042	16.23	122.	12.97
13.2	22.85	.1	.3	2.465	.1217	.9926	22.7	1.	1.015	1.	3.015	21.8	21.8	21.8	37.8	3.315	.6	.80	30.25	32.8	98.5	311.25	3578.25	76.	3654.3	3267	89.35	97.5	2.56	21.	128.	18.52
14.5	25.1	.08	.24	2.71	.0885	.9961	25.05	1.35	1.33	1.3	3.98	27.5	26.8	27.25	47.15	4.22	.5315	.8471	39.93	42.5	153.3	366.05	4681.05	127.5	4808.6	4315	89.75	97.	3.095	27.45	140.8	30.37
15.8	27.35	.09	.27	2.95	.0915	.9958	27.33	1.6	1.6	1.6	4.8	31.8	31.8	31.6	55.	5.07	.4965	.8681	47.75	50.4	208.5	421.25	5586.25	179.7	5766.	5165	89.5	96.75	3.36	32.77	152.5	41.2
17.5	30.3	.09	.27	3.27	.0825	.9966	30.25	1.98	1.93	1.88	5.79	36.7	36.7	36.5	63.5	6.06	.476	.8795	55.85	59.25	277.5	490.25	6525.25	248.	6773.3	6035	89.	96.	4.17	38.28	167.5	55.1
18.7	32.35	.11	.33	3.495	.0944	.9955	32.45	2.275	2.28	2.25	6.805	42.65	42.4	42.2	73.5	7.135	.4415	.8973	66.	69.7	372.5	585.25	7715.25	243.5	8057.8	7130	88.5	95.5	4.715	45.25	178.5	65.3
21.3	36.9	.12	.36	3.98	.0904	.9959	36.83	2.575	2.55	2.52	7.645	47.6	48.6	48.	83.35	8.005	.4415	.8973	74.8	79.1	478.5	691.25	8771.25	442.	9213.3	8080	87.75	94.5	5.83	51.4	198.	83.35
23.	39.8	.14	.42	4.3	.0977	.9952	39.9	2.75	2.8	2.77	8.32	52.5	52.75	51.2	90.4	8.74	.438	.8989	81.35	86.	563.	775.75	9555.75	522.5	10078.3	8780	87.	94.	6.38	56.	209.	93.5
25.3	43.75	.17	.51	4.725	.1079	.9942	43.65	3.12	3.14	3.1	9.36	58.15	58.85	57.2	100.8	9.87	.4325	.9016	91.	96.5	700.	912.75	10742.75	657.5	11400.3	9830	86.25	93.75	6.78	63.1	224.	107.5
27.2	47.1	.18	.54	5.08	.1062	.9943	46.85	3.25	3.35	3.25	9.85	62.2	63.5	60.5	107.7	10.39	.435	.9006	97.	102.8	798.	1010.75	11485.75	747.5	12233.3	10475	85.75	93.25	7.25	67.4	232.4	115.3

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RUN N°6

CONSTANT ROTOR SPEED – 208 V-60~

SYNCHRONOUS MOTOR LOAD.

SYNCHRONOUS MOTOR								SYNCHRONOUS MOTOR – GENERATOR.								INDUCTION GENERATOR.																			
I_4	Equiv. Single Phase Current	Power per Phase.	Total Power	Apparent Power.	Power Factor	Induct-ance Factor.	Wattless Current	I_5	Equiv. Single Phase Current	Power per Phase	Total Power	Apparent Power.	Power Factor	Induct-ance Factor.	Wattless Current	Power Current	I_1	I_2	I_3	Equiv. Single-Phase Current	Total Power	Apparent Power.	Power Factor	Induct-ance Factor	Power Current	Wattless Current	Rotor Current	Stator Copper Loss.	Total Stator Loss.	Rotor Power.	Rotor Copper Loss.	Input Watts.	Output Watts.	Eff.	Frq. of Circuit.	Slip.	Rotor Torque	No Load Voltage	Regulation
Amps.	Amps.	K.W.	K.W.	K.V.A	cos. θ	sin. θ	Amps.	Amps.	Amps.	K.W.	K.W.	K.V.A	cos. θ	Sin. θ	Amps.	Amps.	Amps.	Amps.	Amps.	Amps.	K.W.	K.V.A.	cos. θ	sin. θ	Amps.	Amps.	Amps.	Watts.	Watts.	Watts.	Watts.	Watts.	Watts.	%	Alternations.	%	Lbs. Ft.	Volts.	%
34.4	59.55	.21	.63	11.97	.0526	.9986	33.46	18.6	32.25	.6	1.8	6.49	.277	.9609	31.	7.35	19.5	19.6	19.5	32.8	2.43	6.6	.368	.9298	12.05	30.4	16.5	74.	850.	3211	13.9	3285	2421	73.7	118.75	1.055	19.2	204.1	2.05
31.3	53.9	.175	.525	10.83	.0485	.9988	33.75	13.5	23.41	.95	2.85	4.72	.604	.7969	18.65	14.18	20.6	21.1	21.2	36.4	3.375	7.325	.46	.8870	16.75	32.3	20.1	91.	867.	4242.	28.35	4270	3375	78.	118.75	1.055	24.83	216.5	6.25
27.7	47.95	.16	.48	9.64	.0489	.9987	47.8	12.65	21.9	1.3	3.9	4.4	.886	.4637	9.55	19.4	22.9	23.1	22.75	39.7	4.36	7.95	.5495	.8365	21.8	33.2	26.	108.2	884	5376.	37.6	5414	4492	83.15	118.25	1.48	31.59	221.	10.5
26.65	46.15	.16	.48	9.24	.0518	.9987	46.	14.5	25.13	1.6	4.8	5.08	.944	.33	8.3	23.7	24.7	25.2	24.75	43.15	5.28	8.675	.608	.7939	26.21	34.21	31.	128.	904.	5994.	67.9	6062	5090	84.	118.25	1.48	35.18	228.	14.
26.55	45.75	.15	.45	9.155	.0491	.9988	45.45	19.5	33.8	1.8	5.4	6.8	.795	.6067	20.5	26.85	26.7	27.	25.7	45.8	5.85	9.22	.635	.7725	29.1	35.4	34.	144.2	920.2	6782.	81.7	6864	5862	85.4	118.25	1.48	39.6	233.9	17.95
24.6	42.5	.125	.375	8.565	.0438	.999	42.5	23.6	40.95	2.28	6.84	8.24	.83	.5577	22.8	33.9	30.7	31.2	30.1	53.1	7.215	10.69	.676	.7378	35.9	39.2	41.2	194.	970.	8195.	102.	8297	7225	87.	117.75	1.915	48.	255.	27.5
24.6	42.6	.13	.39	8.565	.0455	.999	42.5	27.	46.75	2.67	8.01	9.4	.854	.5203	24.42	39.9	33.7	34.2	33.6	58.55	8.4	11.6	.7225	.6914	42.35	40.5	48.1	235.5	1011.5	9557.	163.5	9720	8545	88.	117.5	2.125	56.15	262.5	31.25
22.7	39.3	.12	.36	7.9	.0455	.999	39.2	29.	50.3	3.15	9.45	10.12	.934	.357	17.95	47.	37.4	37.2	36.6	64.2	9.81	12.9	.762	.6476	49.35	41.55	56.	283.5	1039.5	11210.	221.5	11431	10130	88.75	117	2.56	65.8	267.5	33.75
21.6	37.4	.1	.3	7.52	.0399	.9992	37.35	33.1	57.45	3.75	11.25	11.55	.975	.2224	12.75	55.95	43.3	43.65	42.	74.4	11.55	14.95	.7725	.6350	57.5	47.2	64.2	380.	1156.	12716.	290.	13006	11560	88.9	117	2.56	74.55	283.5	44.75
21.6	37.4	.1	.3	7.62	.0399	.9992	37.35	39.	67.5	4.45	13.35	13.6	.9815	.1917	12.9	66.2	49.5	49.85	48.	85.05	13.65	17.1	.7985	.602	68.	51.2	75.2	499.	1275.	14955.	399.	15354	13680	88.5	116.75	2.785	87.6	301.	50.5

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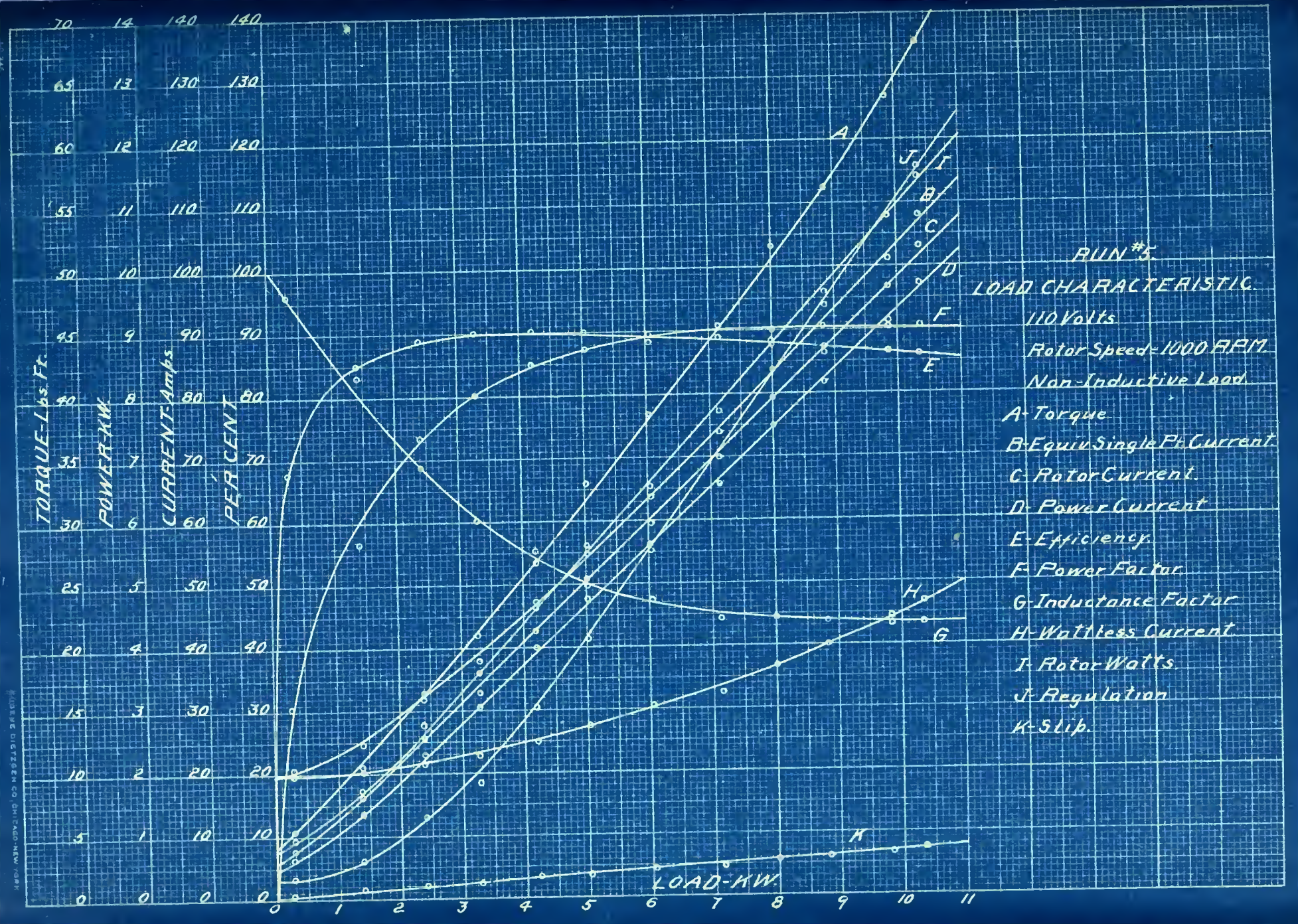
RUN #5.
LOAD CHARACTERISTIC.
110 Volts.
Rotor Speed = 1000 R.P.M.
Non-Inductive Load.
A- Torque.
B- Equiv. Single Ph. Current.
C- Rotor Current.
D- Power Current.
E- Efficiency.
F- Power Factor.
G- Inductance Factor.
H- Wattless Current.
I- Rotor Watts.
J- Regulation.
K- Slip.
TORQUE-Lbs. Ft.
POWER-KW.
CURRENT-Amps.
PER CENT
LOAD-KW.
A
B
C
D
E
F
G
H
J
K
0 1 2 3 4 5 6 7 8 9 10 11
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140

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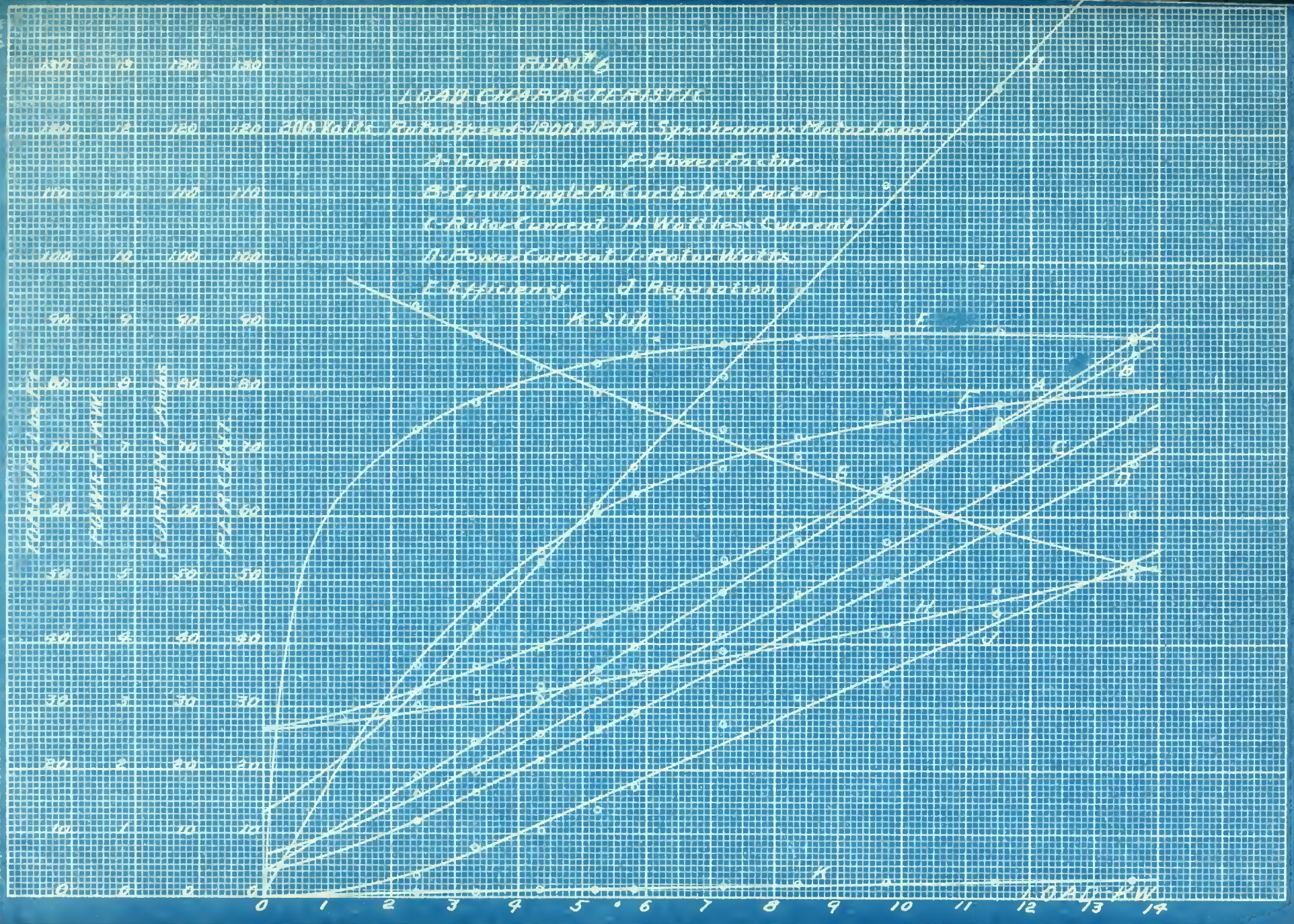
Figure 2
Load Characteristic
2200 Volts Three-Phase 60 Cycles Synchronous Motor Load
A Torque
B Line Amperes
C Output
D Power Factor
E Efficiency
F Speed
G Power Input
H Watts Lost
K Slip
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
KW

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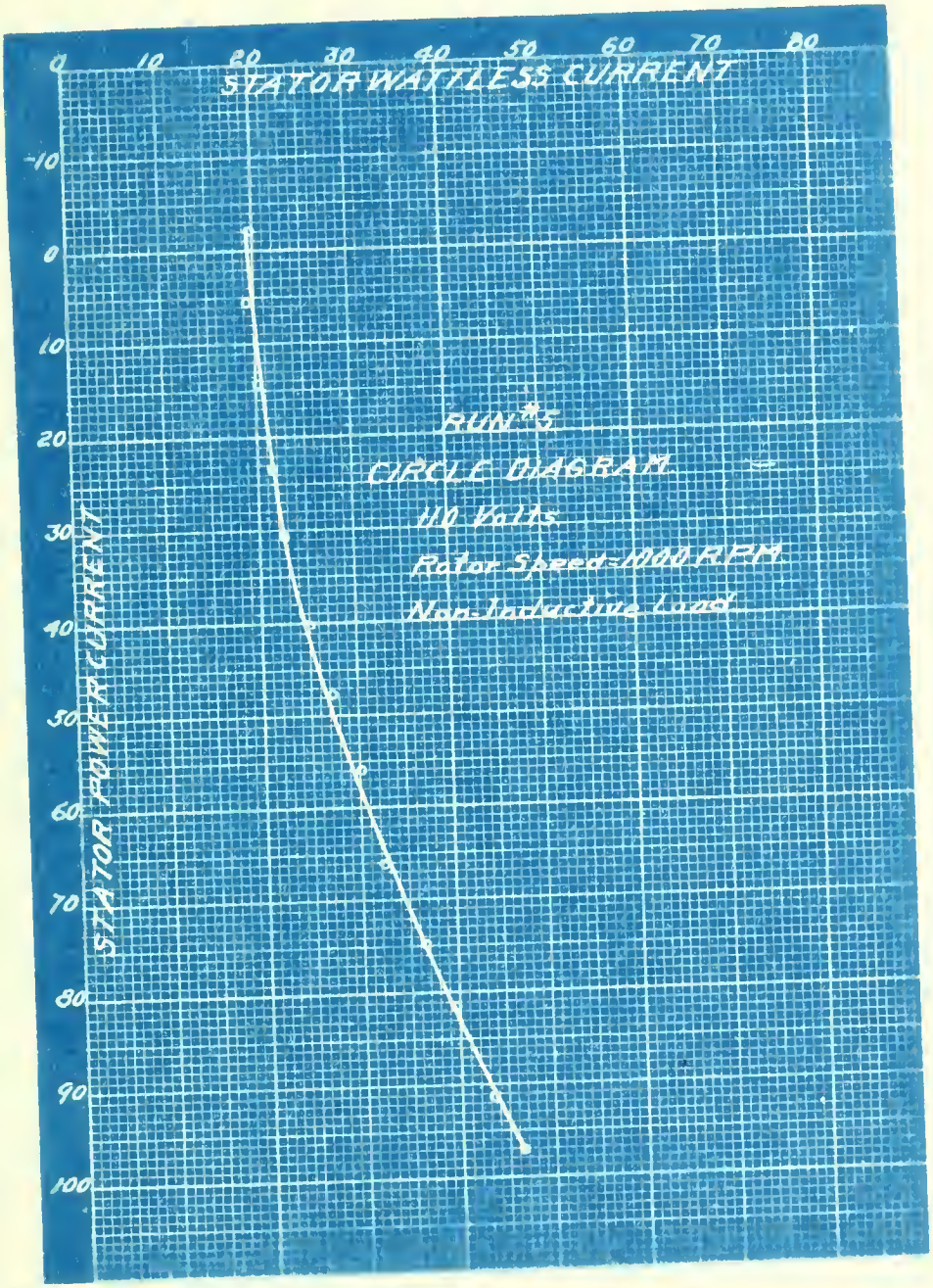
STATOR WATTLESS CURRENT
0
10
20
30
40
50
60
70
80
-10
0
10
20
30
40
50
60
70
80
90
100
STATOR POWER CURRENT
RUN #3
CIRCLE DIAGRAM
110 Volts
Rotor Speed-1000 R.P.M.
Non-Inductive Load

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SUMMARY OF RESULTS. RUN #5

The object of this run was to compare the characteristics obtained at 110 volts, 60 cycles and those obtained at 110 volts, 50 cycles. Contrary to expectations the efficiencies obtained under these two conditions differ but slightly. One would expect that the lower frequency would, because of the lowering of the iron losses, increase the efficiency more than is the case. The fixed losses as measured experimentally are less at 50 cycles but the difference in the fixed losses is not sufficiently great to cause a marked increase in the efficiency. From the regulation obtained in the run, it would seem that the lowering of the frequency makes the regulation poorer, as it reaches a maximum value of over two hundred percent.

SUMMARY OF RESULTS. RUN #6.

The object of this run was to determine the performance of the induction generator when supplying a load giving other than unity power factor. A. synchronous motor generator furnished such a load. We endeavored to keep the excitation of this motor generator set so low that the load would be inductive and not condensive.

It is most interesting to note the variation of the wattless current in such a system. There are three different wattless currents in the system as indicated by our instruments. The wattless current in the synchronous exciter circuit is obtained from the wattmeter and ammeter in that circuit. Similarly,

the wattless current in the circuit of the synchronous motor generator set will be given by the wattmeter and ammeter in that circuit. At the generator another value of wattless current may be obtained from the wattmeters in the other two circuits and the ammeters at the generator. The data, calculated as above, shows that the wattless current at the synchronous exciter decreases with load. This is also the case at the motor generator set, while at the generator the wattless current increases with load. However, at light loads the wattless current at the synchronous exciter is not very far different from the sum of the wattless currents at the generator and at the motor generator set, which would indicate that the synchronous exciter is supplying wattless current both to the induction generator and to the motor generator. As the load increases, the power factor of the motor generator increases, and the amount of wattless current, supplied by the synchronous exciter to the motor generator, diminishes.

We found that when making this run that we were unable to keep up the system voltage by means of the synchronous exciter field, but at the higher loads we had to resort to changing the field of the synchronous motor generator set. Therefore it is very probable that for the higher loads the synchronous motor driving the D. C. generator was over excited, and consequently furnished wattless current to the induction generator. This is borne out by the results obtained for the higher

loads, for instance, at the greatest load wattless current at thegenerator is not very far different from the sum of the wattless currents at the synchronous exciter and at the synchronous motor generator.

As to the generator characteristics under these conditions it seems as though the nature of the load has but little effect, providing there is an over excited machine also in the circuit for exciting purposes. The efficiency is slightly lower than that obtained in the previous runs, but with this exception the characteristics compare favorably with those obtained with a lamp load.

RUN #7. LOAD CHARACTERISTICS

Constant Excitation. Rotor Speed Constant at 1200 R.P.M.

Synchronous Motor Load.

SY	
I_4	Equiv Single Phas Curre
Amps.	Amp
8.25	14.27
9.2	15.91
9.25	16.
9.2	15.91
9.5	16.43
9.75	16.87
10.7	18.51

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EUGENE DIETZGEN CO., CHICAGO-NEW YORK.
NO 346

RUN Nº 7.

CONSTANT ROTOR SPEED - 60 ~

SYNCHRONOUS MOTOR LOAD.

CONSTANT EXCITATION OF SYNCHRONOUS MACHINES.

SYNCHRONOUS MOTOR								SYNCHRONOUS MOTOR-GENERATOR														INDUCTION GENERATOR																
I_4	Equiv. Single Phase Current	Power per Phase.	Total Power.	Apparent Power.	Power Factor.	Induct-ance Factor.	Wattless Current.	I_5	Equiv. Single Phase Current	Power per Phase.	Total Power.	Apparent Power.	Power Factor.	Induct-ance Factor.	Wattless Current.	Power Current.	E.	I_1	I_2	I_3	Equiv. Single Phase Current.	Total Power.	Apparent Power.	Power Factor.	Induct-ance Factor.	Power Current.	Wattless Current.	Rotor Current.	Stator Copper Loss.	Total Stator Loss.	Rotor Power.	Rotor Copper Loss.	Input	Output	Eff.	Freq. of Circuit.	Slip.	Rotor Torque.	No Load Voltage.	Regulation.
Amps.	Amps.	K.W.	K.W.	K.V.A.	cos. θ	sin. θ	Amps.	Amps.	Amps.	K.W.	K.W.	K.V.A.	cos. θ	sin. θ	Amps.	Amps.	Volts.	Amps.	Amps.	Amps.	Amps.	K.W.	K.V.A.	cos. θ	sin. θ	Amps.	Amps.	Amps.	Watts.	Watts.	Watts.	Watts.	Watts	Watts	%	Alternations	%	Lbs. Ft.	Volts.	%
8.25	14.275	.56	1.08	2.865	.377	.9262	13.2	7.6	13.17	.52	1.56	2.646	.589	.8082	10.63	7.78	201	19.75	19.	18.75	33.2	2.64	6.67	.396	.9182	13.15	30.45	17.	75.8	851.8	3494	20.4	3514	2642	75.3	119	.83	10.5	205	1.99
9.2	15.91	.3	.9	2.99	.301	.9536	15.19	11.6	20.1	.8	2.4	3.780	.635	.7725	15.52	12.76	188	21.2	19.7	19.75	35.	3.3	6.68	.502	.8649	17.37	30.2	21.5	94.2	860.2	4160	32.6	4193	3300	78.8	119	.83	14.43	204	8.32
9.25	16.	.39	1.17	2.994	.391	.9204	14.72	13.6	23.58	1.1	3.303	4.410	.749	.6626	15.6	17.66	187	23.2	20.75	20.6	36.85	4.473	6.89	.649	.7608	23.9	28.03	27.9	93.2	869.2	5334	55.	5389	4465	83.	118.75	1.05	21.1	190	1.67
9.2	15.91	.28	.84	2.99	.281	.9596	15.3	14.6	25.32	1.225	3.675	4.760	.772	.6356	16.1	19.54	188	23.7	21.75	22.1	39.	4.515	7.34	.616	.7877	24.02	30.75	28.	104.6	880.6	5401	55.4	5456	4520	82.9	118.5	1.26	21.37	209	11.2
9.5	16.43	.27	.81	3.045	.266	.9639	15.82	17.2	29.9	1.68	5.04	5.530	.912	.4102	12.22	21.2	185.5	27.65	26.	26.	46.	5.85	9.53	.686	.7276	31.6	33.45	35.7	146.	922.	6792	90.	6827	5860	85.4	118.	1.69	29.	222	19.7
9.75	16.67	.275	.825	3.120	.264	.9645	16.3	19.8	34.3	1.98	5.94	6.345	.937	.3494	11.97	22.15	185.	29.25	28.	27.6	49.	6.765	9.06	.747	.6648	36.6	32.6	40.7	165.3	941.3	7711	108.1	7819	6770	86.6	118.	1.69	34.2	219	18.35
10.1	18.51	.25	.75	3.385	.222	.9750	18.1	21.9	37.98	2.2	6.6	6.950	.95	.3125	11.87	24.06	183.	30.7	30.6	29.5	52.4	7.35	9.59	.767	.6417	40.8	33.55	44.2	189.	965.	8325	117.5	8442	7360	87.3	117.25	2.34	37.6	225	22.9

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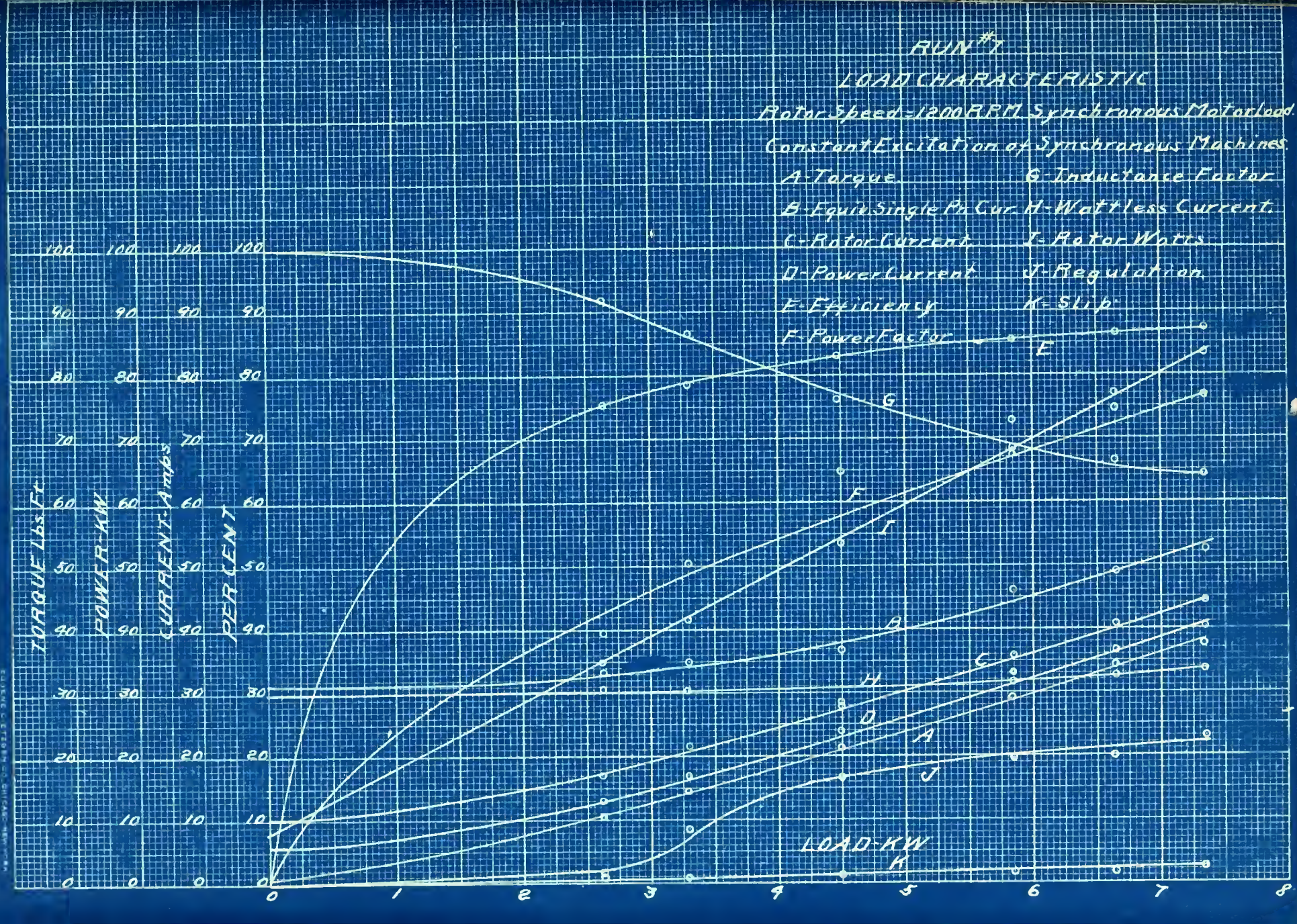
RUN #7
LOAD CHARACTERISTIC
Rotor Speed = 1200 R.P.M. Synchronous Motor load.
Constant Excitation of Synchronous Machines.
A-Torque
B-Equiv. Single Ph. Cur.
C-Rotor Current
D-Power Current
E-Efficiency
F-Power Factor
G-Inductance Factor
H-Wattless Current
I-Rotor Watts
J-Regulation
K-Slip
TORQUE Lbs. Ft.
POWER-KW
CURRENT-AMPS
PER CENT
LOAD-KW
0
1
2
3
4
5
6
7
8
10
20
30
40
50
60
70
80
90
100

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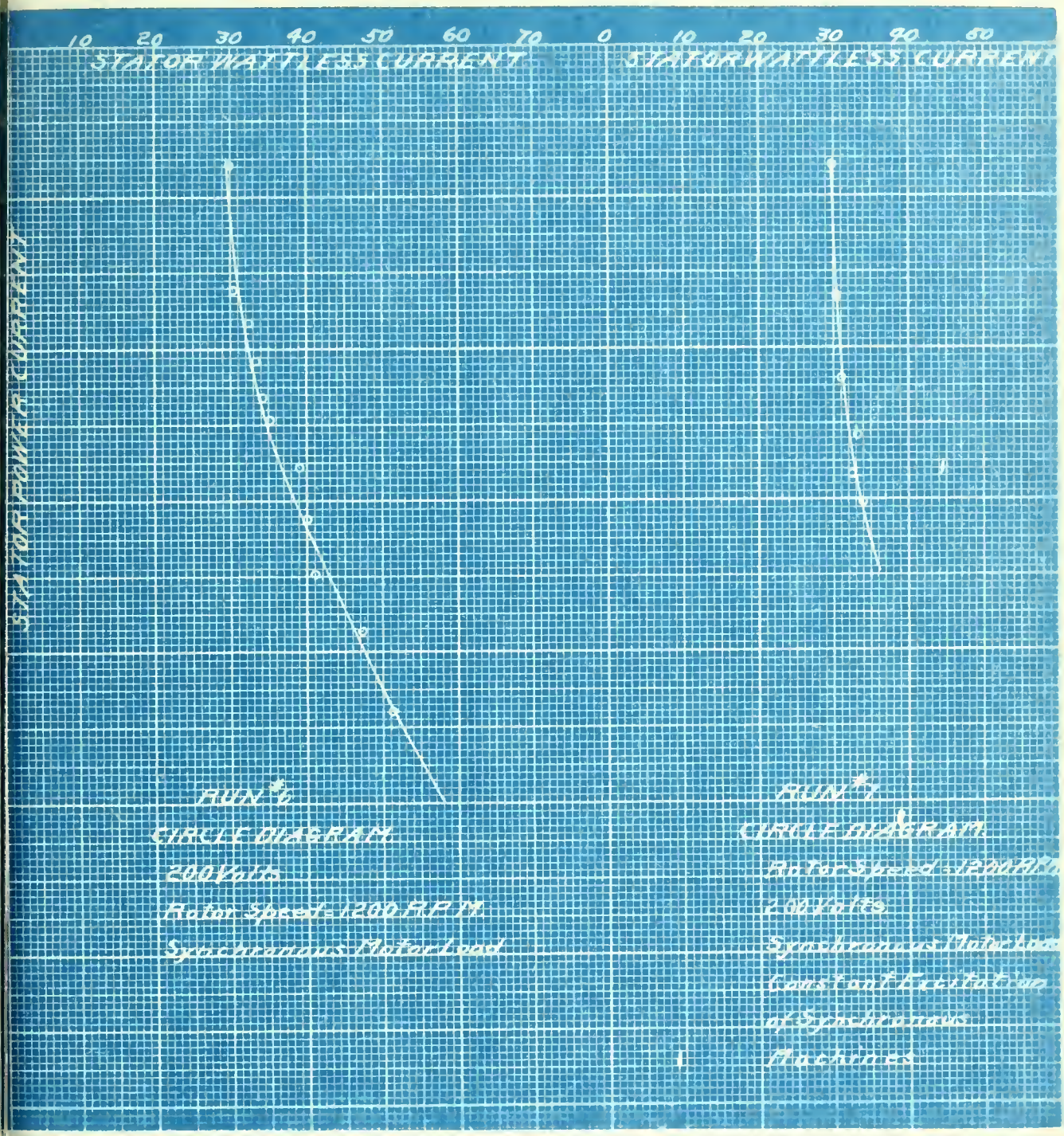
10 20 30 40 50 60 70
STATOR WATTLESS CURRENT
0 10 20 30 40 50
STATOR WATTLESS CURRENT
STATOR TERMINAL VOLTAGE
RUN #2
CIRCUIT OPEN AT
200 Volts
Rotor Speed = 1200 R.P.M.
Synchronous Motor at Load
RUN #3
CIRCUIT CLOSED AT
Rotor Speed = 1200 R.P.M.
120 Volts
Synchronous Motor Load
Constant Excitation
of Synchronous
Machines

Run #8. PARALLEL OPERATION

SYN			
I_1'	I_2'	I_3'	Equiv. Single Phase Curren
Amps.	Amps.	Amps.	Amps
30.83	30.4	33.7	54.7
17.56	18.3	23.	34.
16.48	16.6	19.3	30.2
17.5	18.37	18.3	31.3
16.7	17.23	18.3	30.16

RUN N-6

PARALLEL OPERATION - 180 V. - 60 ~.

NON-INDUCTIVE LOAD.

SYNCHRONOUS GENERATOR											INDUCTION GENERATOR										DIVISION OF LOAD.	
I_1'	I_2'	I_3'	Equiv. Single Phase Current	W_4	W_5	W_6	Total Power.	Apparent Power.	Power Factor.	Induct. ance Factor.	Wattless Current.	I_1	I_2	I_3	Equiv. Single Phase Current	Induct. ance Factor.	Power Factor	Power Current.	Total Power.	Speed of Rotor.	Slip.	Load on Induction Generator.	Load on Synchronous Generator.
Amps.	Amps.	Amps.	Amps.	K.W.	K.W.	K.W.	K.W.	K.V.A.	cos θ	sin θ	Amps.	Amps.	Amps.	Amps.	Amps.	sin θ	cos θ	Amps.	K.W.	R.P.M.	%	%	%
30.93	30.4	33.7	54.75	3.13	2.825	2.825	8.82	9.86	.882	.4713	25.8	15.1	14.9	16.7	26.85	.96	.2798	7.52	1.354	1204	.333	13.3	86.7
17.56	18.3	23.	34.	1.75	1.392	1.335	4.477	6.12	.732	.6813	23.15	18.9	19.7	24.75	37.1	.6235	.7819	29.	5.22	1215	1.25	38.25	61.75
16.48	16.6	19.3	30.27	1.00	.86	.854	2.714	5.45	.4975	.8675	26.3	22.	22.15	25.75	40.3	.652	.7582	30.6	5.51	1222	1.833	67	33.
17.5	18.37	18.3	31.3	.37	.3715	.354	1.095	5.635	.1943	.981	30.7	29.25	30.7	30.6	52.3	.5865	.81	42.4	7.64	1230	2.5	87.5	12.5
16.7	17.23	18.3	30.15	.05	.0471	.0457	.1428	5.43	.0263	.9997	30.141	31.5	32.7	34.5	56.8	.531	.8474	48.2	8.68	1232	2.666	98.4	1.6

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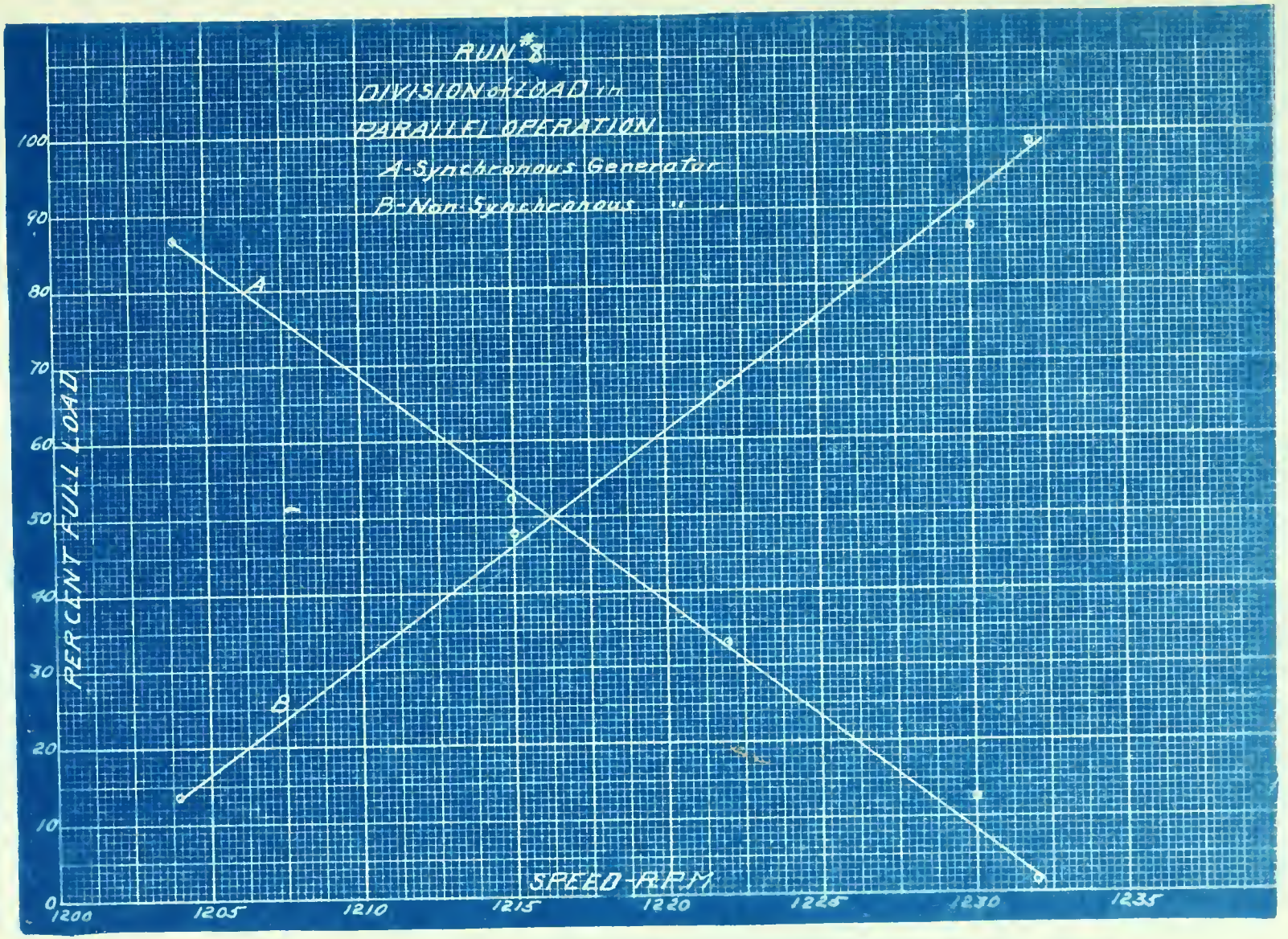
RUN #8
DIVISION of LOAD in
PARALLEL OPERATION
A-Synchronous Generator
B-Non-Synchronous "
PERCENT FULL LOAD
SPEED-R.P.M.
100
90
80
70
60
50
40
30
20
10
0
1200
1205
1210
1215
1220
1225
1230
1235
A
B

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SUMMARY OF RESULTS:

The object of this run was to note the division of load between an induction and synchronous generator when operating in parallel and the conditions affecting the same.

Owing to the fact that sufficient instruments were not available to measure the current in each load, and the power in each phase, we used an ammeter in each lead from the induction generator and assumed that these readings would be indicative of the degree of unbalancing on each phase of the load a wattmeter at the synchronous generator was connected in one phase line the pressure coil from that phase line to neutral. Only one ammeter was available for use at the synchronous generator and measured the current in one phase line. In order to obtain the current in the other phase lines, the ratio of the current indicated by this ammeter to that measured in the same phase line at the induction generator, was obtained. This ratio is also the ratio of the current in any other phase line at the synchronous machine to that in the same phase line at the induction generator, so that the current in the two remaining phase lines at the synchronous machine may be obtained by multiplying the current in the correspondending Phase lines at the induction generator, by the above ratio. As the power per phase is propostional to the current in the same phase line, the voltage remaining constant, the ratio of th

Run #9. H E A T T E S T

HEAT TEST.

Time.	TEMPERATURE.				RISE.		
	Ventilating Ducts.	Laminations	Stator Winding.	Room	Ventilating Ducts.	Laminations.	Stator Winding
	C.°	C.°	C.°	C.°	C.°	C.°	C.°
9:00	36.3	33.7	35.5	26.5	9.8	7.2	9.
9:10	39.2	38.1	37.	26.5	12.7	11.6	10.5
9:20	41.2	41.	39.	27.5	13.7	13.5	11.5
9:30	43.	42.7	39.	26.5	16.5	16.2	12.5
9:40	43.7	44.	39.	25.	18.7	19.	14.
9:50	44.	44.5	39.	25.5	18.5	19.	13.5
10:00	44.2	46.	40.	25.25	18.95	20.75	14.75
10:10	44.2	46.1	40.	25.	19.2	21.1	15.
10:20	45.	46.1	40.	25.	20.	21.1	15.
10:30	45.5	47.	40.5	25.5	20.	21.5	15.
10:40	46.	47.5	40.8	25.	21.	22.5	15.8
10:50	46.	48.	40.8	24.8	21.2	23.8	16.
11:00	46.	48.	41.	24.	22.	24	17.
11:10	46.2	48.1	41.5	24.5	21.7	23.5	17.
11.20	46.	48.1	42.	24.1	21.9	24.	17.9
11:30	45.	47.5	41.2	24.3	20.7	23.2	16.9
11:40	45.	47.	41.	24.	21.	23.	17.
11:50	45.	47.	41.	24.2	20.8	22.8	16.8
12:00	45.2	47.	41.	24.5	20.7	22.5	16.5
12:10	45.5	47.5	41.	24.5	21.	23.	16.5
12:20	45.5	47.5	41.	25.	20.5	22.5	16.
12:30	45.5	47.5	41.	25.	20.5	22.5	16.
12:40	45.5	48.	41.	24	21.5	24.	17.
12:50	45.5	48.	41.	24	21.5	24.	17.
1:00	45.5	47.5	41.	24	21.5	24.	17.

MASS. INST. TECH.
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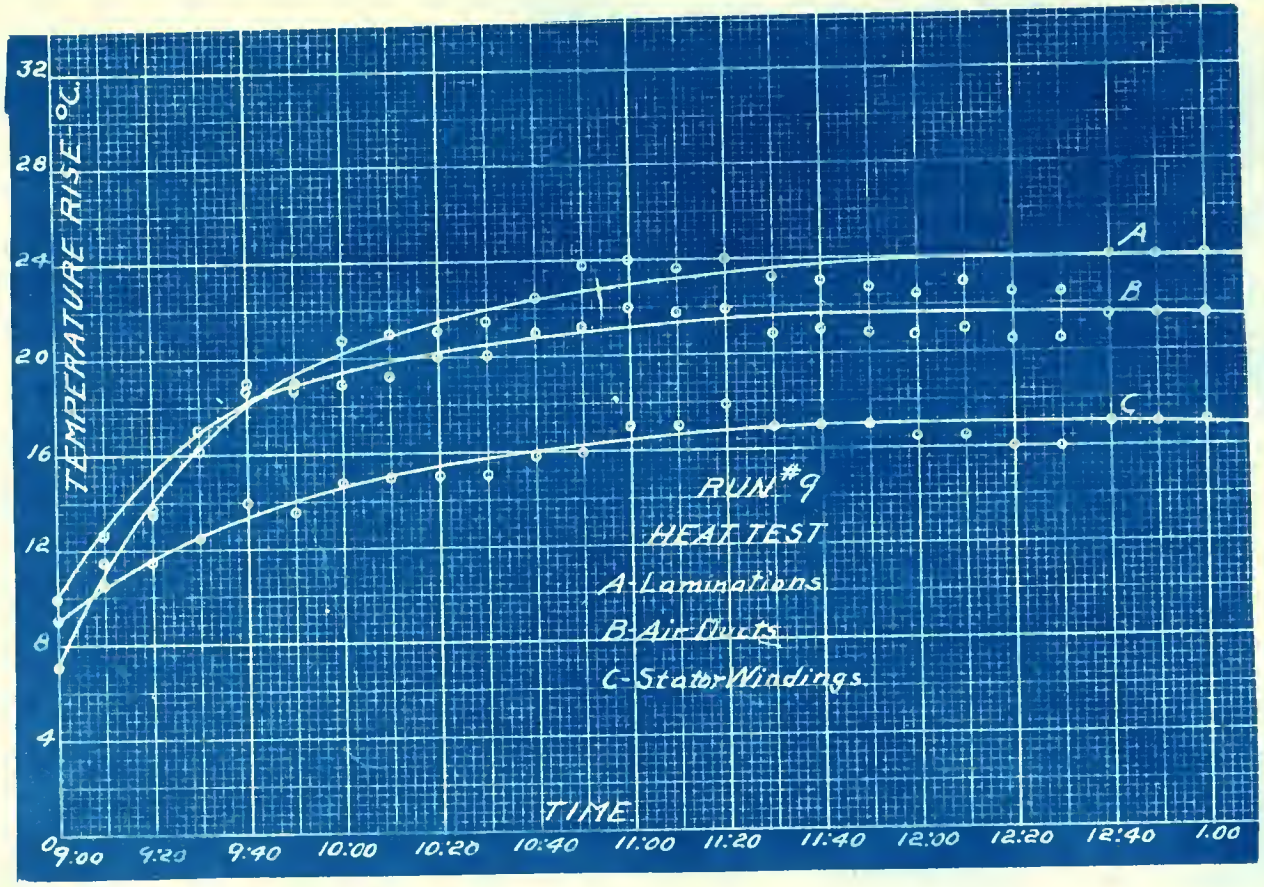
TEMPERATURE RISE °C.
32
28
24
20
16
12
8
4
0
A
B
C
RUN #9
HEAT TEST
A-Laminations
B-Air Ducts
C-Stator Windings
TIME
9:00
9:20
9:40
10:00
10:20
10:40
11:00
11:20
11:40
12:00
12:20
12:40
1.00

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SUMMARY OF RESULTS:

In this run the induction generator was operated at full load for four consecutive hours and the rise of temperature of various portions of the machine was noted. Our results show that the greatest heating occurs in the stator laminations. This rise amounted to twenty five degrees Centigrade. The rise of temperature in the ventilating ducts, which may considered as that of the rotor, was twenty one and a half degrees Centigrade. The temperature rise in the stator windings was seventeen degrees Centigrade. As the allowable temperature rise in this class of machine is given by the A.I.E.E. Standardization Rules as fifty five degrees Centigrade, the actual rise is comparatively low. As the overload capacity of a generator is largely dependent upon the amount of heating, it follows that the induction generator will stand very heavy overloads.

G E N E R A L D I S C U S S I O N

From the experimental results previously obtained and from a study of the literature on the subject the advantage of the induction generator seems to be as follows:

1) High efficiency,- Although our results show as a maximum efficiency ninety percent, it must be remembered that the machine under test was comparatively small and was operated at a comparatively low speed, it would also be advisable to state in this connection that in obtaining the efficiency the power used to excite the synchronous motor was not charged against the generator, as in large distributing systems part of the excitation may be obtained from synchronous motors or converters that are a part of the regular load or from the capacity of the cable lines.

Induction generators of greater capacity, and driven by high speed steam turbines, have given an efficiency of over ninety seven percent. However our results serve to demonstrate that the efficiency of an induction generator is practically independent of the voltage, frequency and the character of the load, which is a decided advantage.

2) Mechanical construction,- As the construction of the induction generator is exactly the same as that of the squirrel cage induction motor, there can be no question as to its simplicity of construction. In large units the difficulty

of obtaining small air gaps may detract from the otherwise excellent mechanical construction of the induction generator.

3) Absence of D. C. fields,- The induction generator is excited by alternating current it is obvious that there can be no direct current fields, which eliminates that most troublesome factor occurring in synchronous machines, namely armature reaction.

4) The induction generator will give a true sine wave for all loads,- Owing to the absence of armature reaction, the waves, both current and E.M.F., are true sine waves, and are not distorted with increase of load. This is a condition only approximated by the synchronous generator at no load.

5) Tends to prevent the effects of harmonics and resonance on the system,- As resonance and harmonics, which are with synchronous machines disturbing elements, are present only when the E.M.F. and current waves are distorted, this type of disturbance is prevented by the induction generator. The induction generator, because it has a true sine wave, acts as a damper and has a tendency to prevent distortion and harmonics. The induction generator is also a protection against power surges, as when short circuited the induction generator looses its voltage and becomes dead.

6) The induction generator is particularly adapted for parallel operation with synchronous generators. This

adaptibil ty is shown by the fact that it is not necessary to synchronize when placing induction generators in parallel with synchronous generators.

7) Control of load by prime mover governor,- As previously mentioned the amount of load carried by an induction generator when operating in connection with other generators, as on a large distributing system, is entirely dependent upon the speed at which the induction generator is driven. Therefore the amount of load carried by the induction generator may be regulated by means of the governing device on the prime mover.

8) Unequal distribution of load between generators does not cause cross currents,- This is an advantage in parallel operation, and because an unequal distribution of load does not cause cross currents, it is possible to divide the load on the machines in any desired proportion.

9) Less power required for excitation than for synchronous machines,- This is particularly true for units of large capacity. Although a certain amount of power is required when an unloaded synchronous motor is used for excitation; it is often the case that in large distributing systems the excitation may be obtained from condensance in the line offrom synchronous motors or converters already in service.

10) Close speed regulation of the prime mover is not essential,- This makes the induction generator particularly applicable for gas engine or turbine driven units.

The most important disadvantages of the induction generator are;

1) Inability to supply a system having a lagging power factor;- This is a serious objection and limits the induction generator to a certain class of systems, those in which condensance or synchronous motors and converters are present. In large systems synchronous motors or converters are generally present and in smaller systems a synchronous motor can be installed.

2) Difficulty of control of magnetizing or exciting current,- If a separate machine is not used for excitation this is a serious objection, for when synchronous converters at distant sub-stations are used, the control of the exciting current is not at the generating station. This would necessitate a system of signals or telephonic communication between the sub-stations and generating station,-

3) The exciting machine or a system furnishing the necessary wattless current must be in operation Before the induction generator will furnish power,- This feature of the induction generator would necessitate in plants consisting entirely of induction generators, some auxillary source of power to start the synchronous exciters. If these exciters are synchronous converters a source of direct current could be used for this purpose and the converters started from the D.C. side. However it is probable that the induction generator will be mainly used

in connection with systems containing synchronous machines, which systems will be in operation before the induction generator is connected in.

PRACTICAL APPLICATION OF THE INDUCTION GENERATOR

While it is very improbable that the induction generator will entirely replace the synchronous generator it is probable that it will find its widest application in parallel operation with synchronous machines in large distributing systems. In many large distributing systems the condensance of the distributing cables is sufficient to furnish the excitation required for an induction generator of considerable capacity with condensance could be profitably used by installing an induction generator.

Another important application has develcped from the recent extended use of turbines as prime movers. Owing to the high speed of turbines direct current generators are not efficient when turbine driven. It is general practice to drive direct current units by slow speed engines. It has been demonstrated that a turbine driven induction generator driving a synchronous converter is more econo ical than a direct current generator of similar capacity driven by a slow speed engine. It is in this connection that the induction generator will doubtless receive a wide application.

Mr. C. P. Stienmetz is a discussion of Mr. Water's paper on the induction generator points cut two important possible applications of the induction generator. The first case is that where water power is operated in parallel with steam power. There are numerous cases where the water power

obtainable is a variable and a steam plant is installed to take care of the power required in excess of that furnished by the water power. In such a case a synchronous machine could be driven by a steam engine at a constant speed and an induction generator could be driven by a water wheel without a governor. As the amount of load carried by the induction generator will depend entirely upon the speed at which it is driven, which in turn will depend upon the available water power, all of the available water power will be utilized and the steam driven unit will be required to carry only that portion of the load which is in excess of that carried by the induction generator.

The other application suggested by Mr. Steinmetz is in connection with the utilization of small water powers. Dr. Steinmetz states that there are on small streams, numerous places where water power is available in quantities too small to warrant the construction of a large power house. He suggests that in case of this nature a small turbine or water wheel connected to an induction generator be used. These sets could be installed at each of these small sources and placed in a small concrete structure and all such installations connected in parallel on a transmission line. As the amount of power taken from each generator would be entirely dependent upon the speed, several such installations could be operated in parallel and would require practically no attention.

CALIBRATION CURVES.

INSTRUMENT INDEX.

Kind of Instrument	Symbol on Data.	No. of Instrument.	Range.	Make.
Ammeter	I_A	63	0-50	Thompson
"	I_1	64	0-100	"
"	I_2	65	0-100	"
"	I_5	70	0-100 with 20to1 Transforme	"
"	I_3 , I_3'	95375	0-100 " " " "	Westinghouse
Voltmeter	E	28	0-250	Weston
Wattmeter	W_4	96	150V - 50 Amps.	"
"	W_6	97	150V - 100 Amps.	"
"	W_1, W_2, W_3	98	150V - 100 Amps.	"

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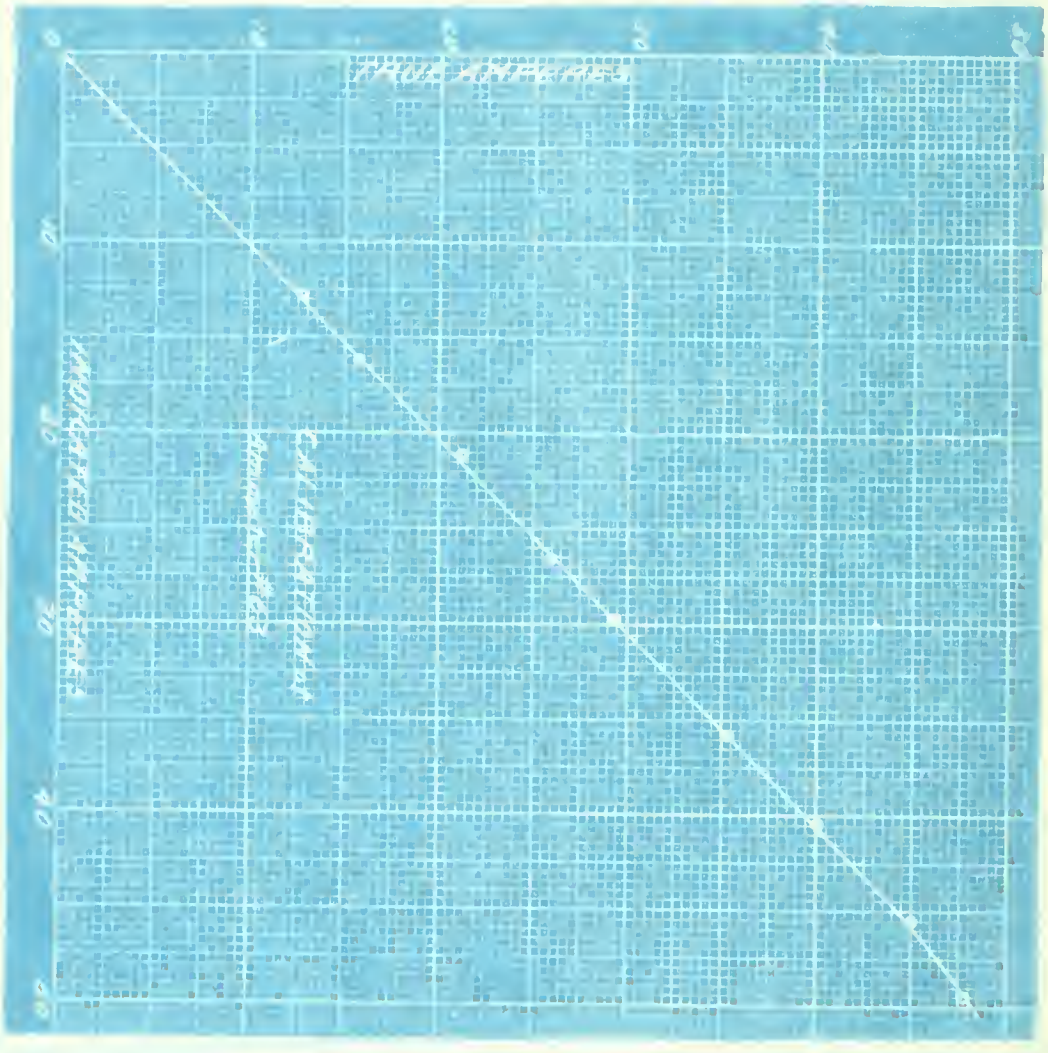

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TRUE AIRSPEED
MULTIPLIED BY
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390

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TRUE AMPERES
INDICATED AMPERES
0
10
20
30
40
50
60
70
Thermocouple
Hot Wire

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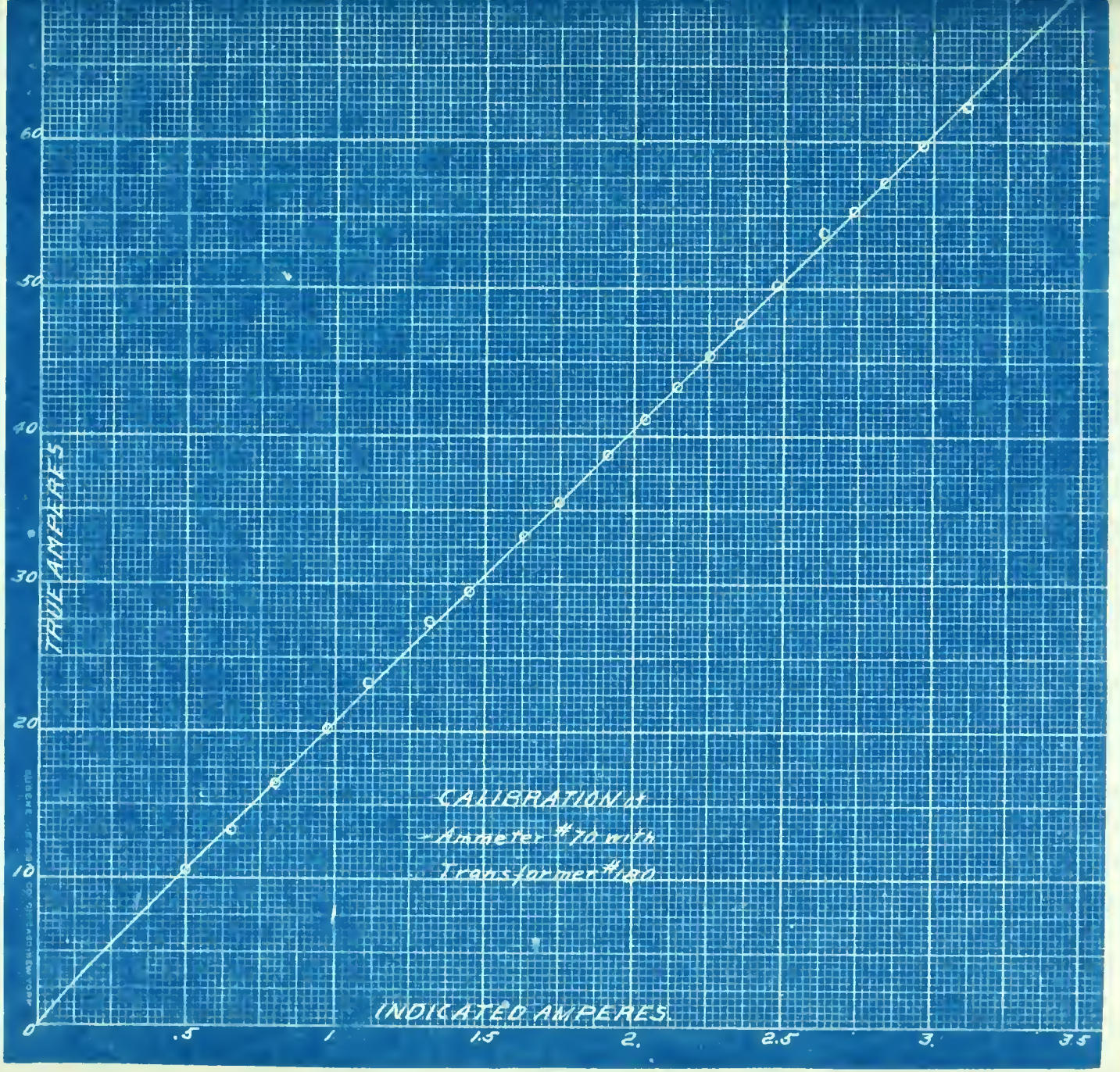
TRUE AMPERES
60
50
40
30
20
10
0
CALIBRATION of
-Ammeter #70 with
Transformer #120
INDICATED AMPERES
.5
1
1.5
2.
2.5
3.
3.5

ARMOUR
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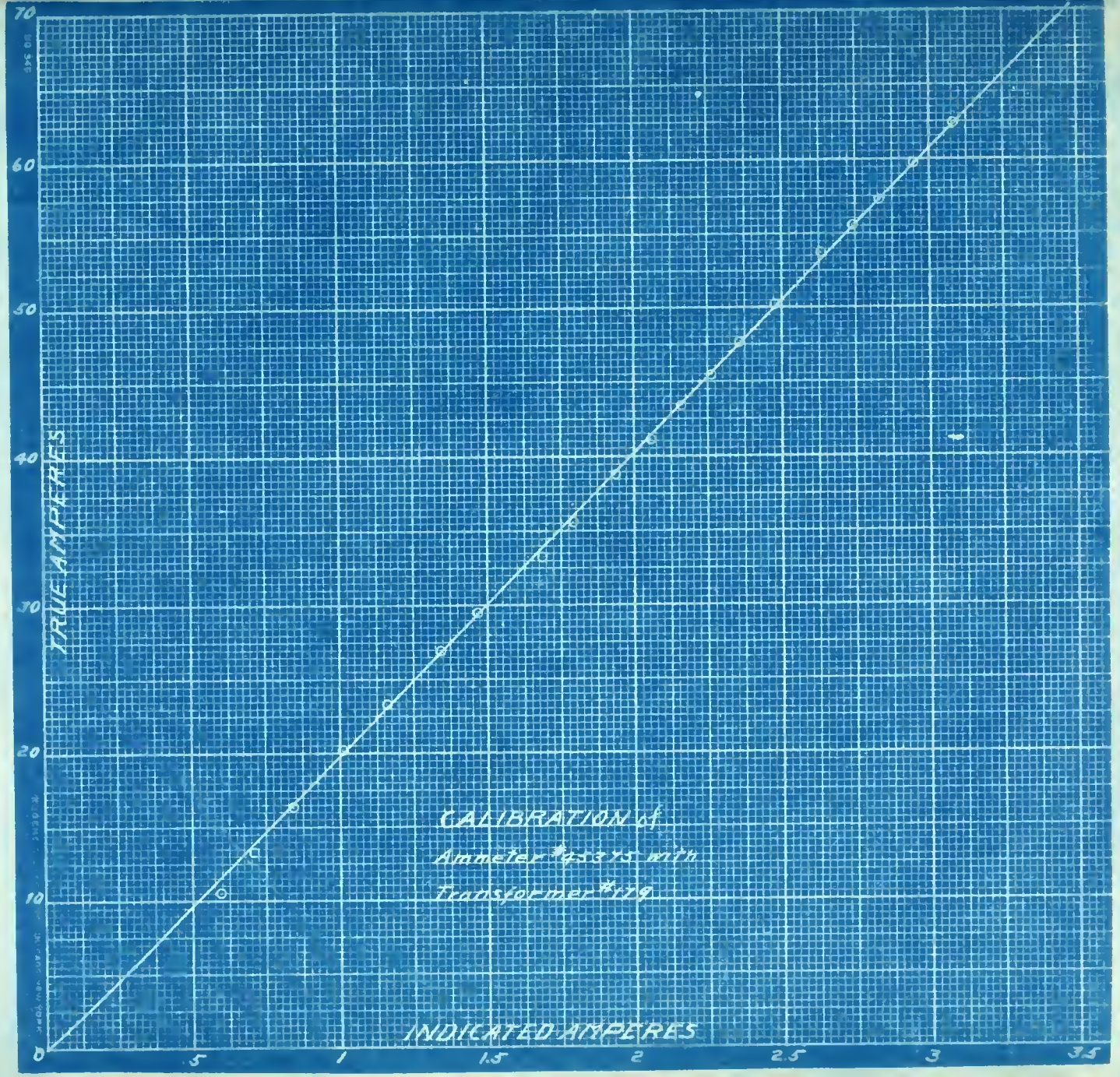
70
60
50
40
30
20
10
0
TRUE AMPERES
CALIBRATION of
Ammeter #5515 with
Transformer #129
INDICATED AMPERES
.5
1
1.5
2
2.5
3
3.5

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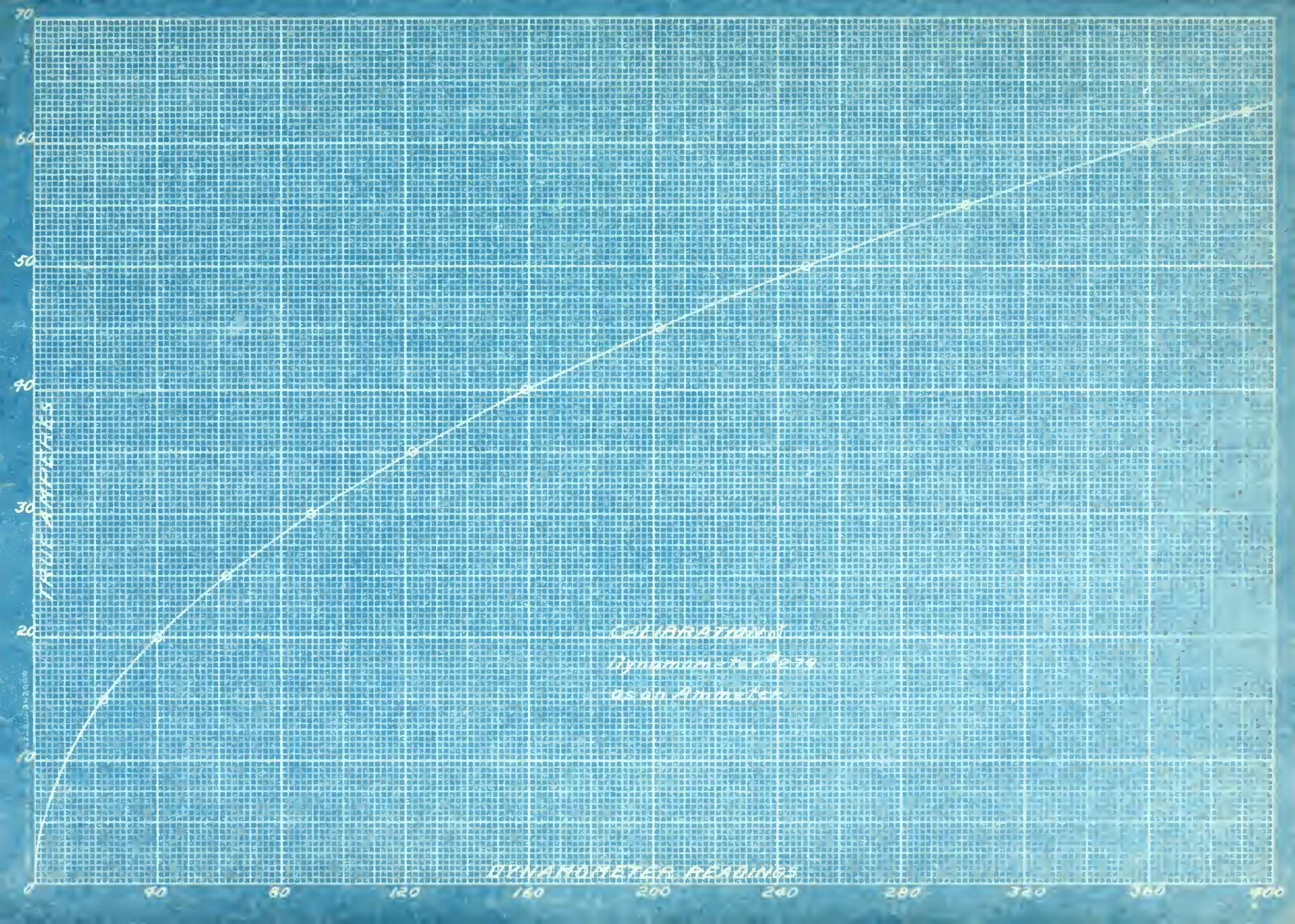
LIBRARY.


70
60
50
40
30
20
10
0
40
80
120
160
200
240
280
320
360
400
CALIBRATION of
Dynamometer Head
as an Ammeter
DYNAMOMETER READINGS

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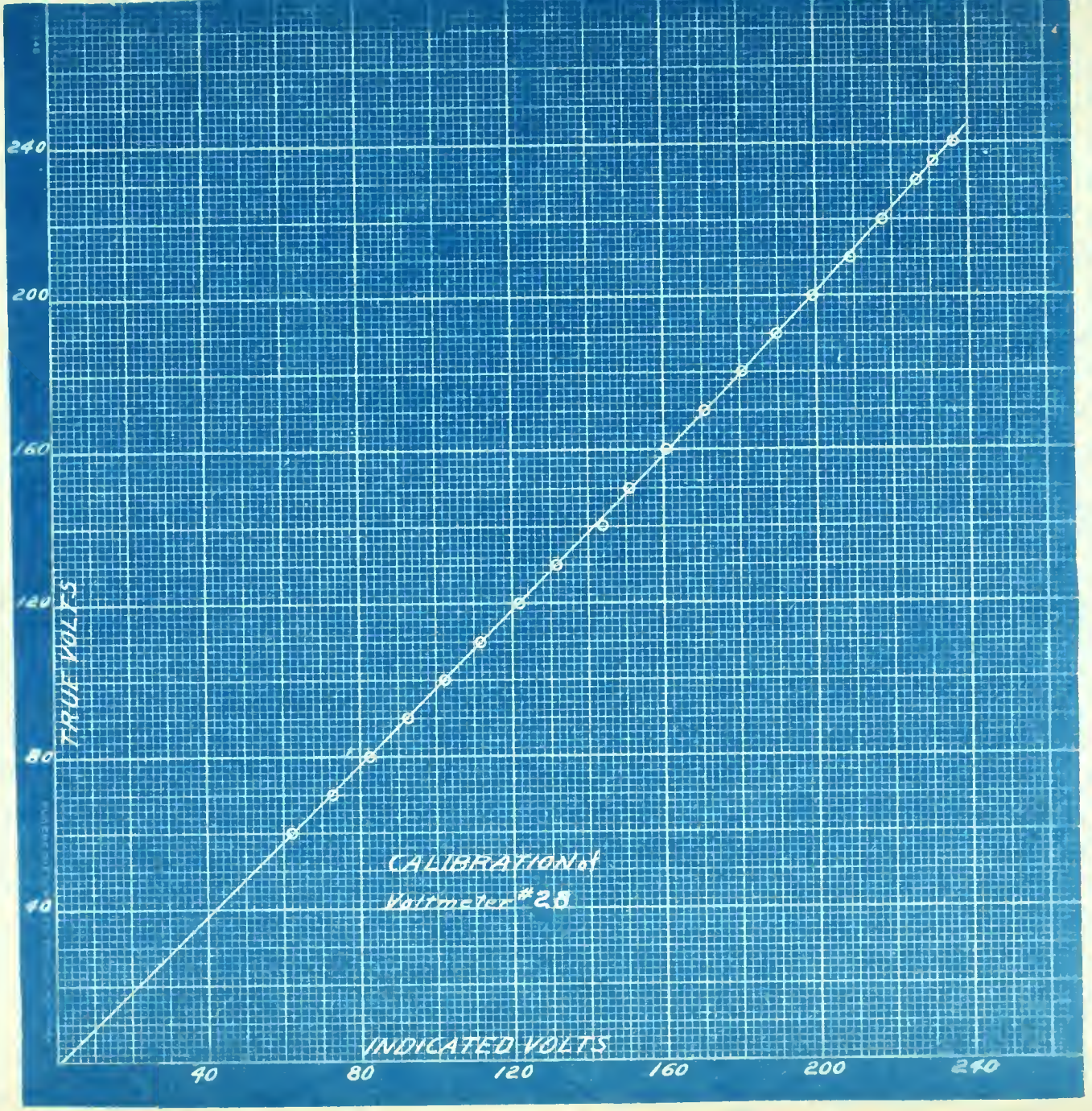
240
200
160
120
80
40
TRUE VOLTS
CALIBRATION of
Voltmeter #28
INDICATED VOLTS
40
80
120
160
200
240

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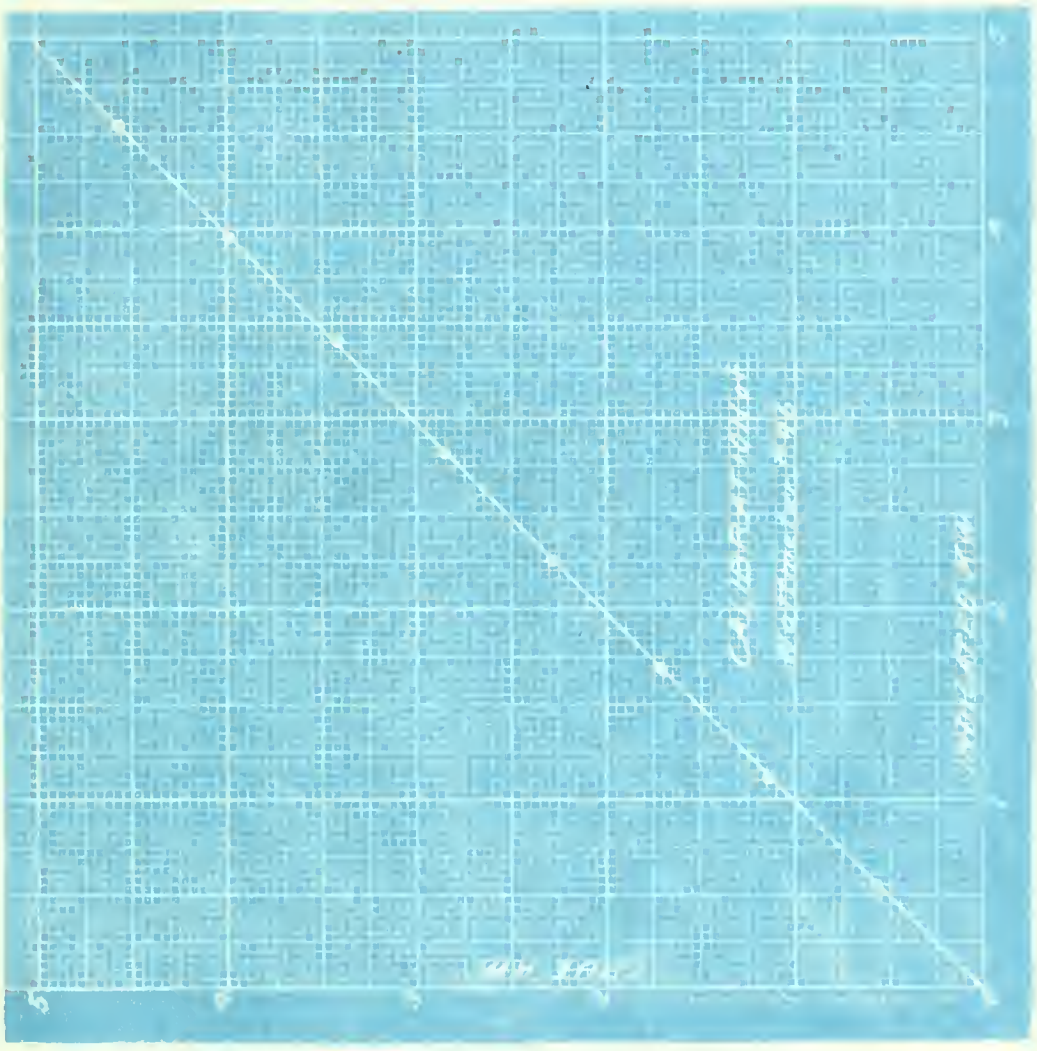

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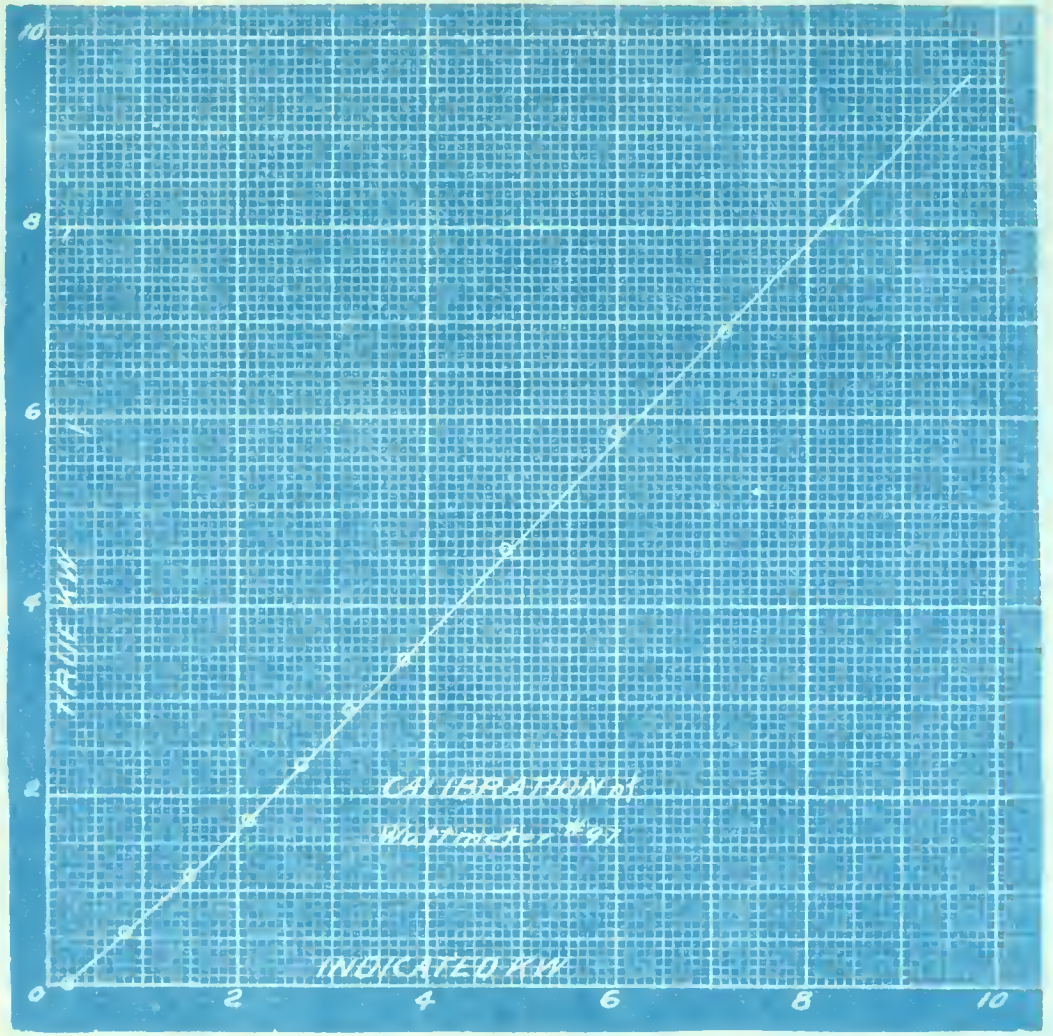
TRUE MM
INDICATED MM
0
2
4
6
8
10
CALIBRATION OF
Watrous #21

ARMOUR
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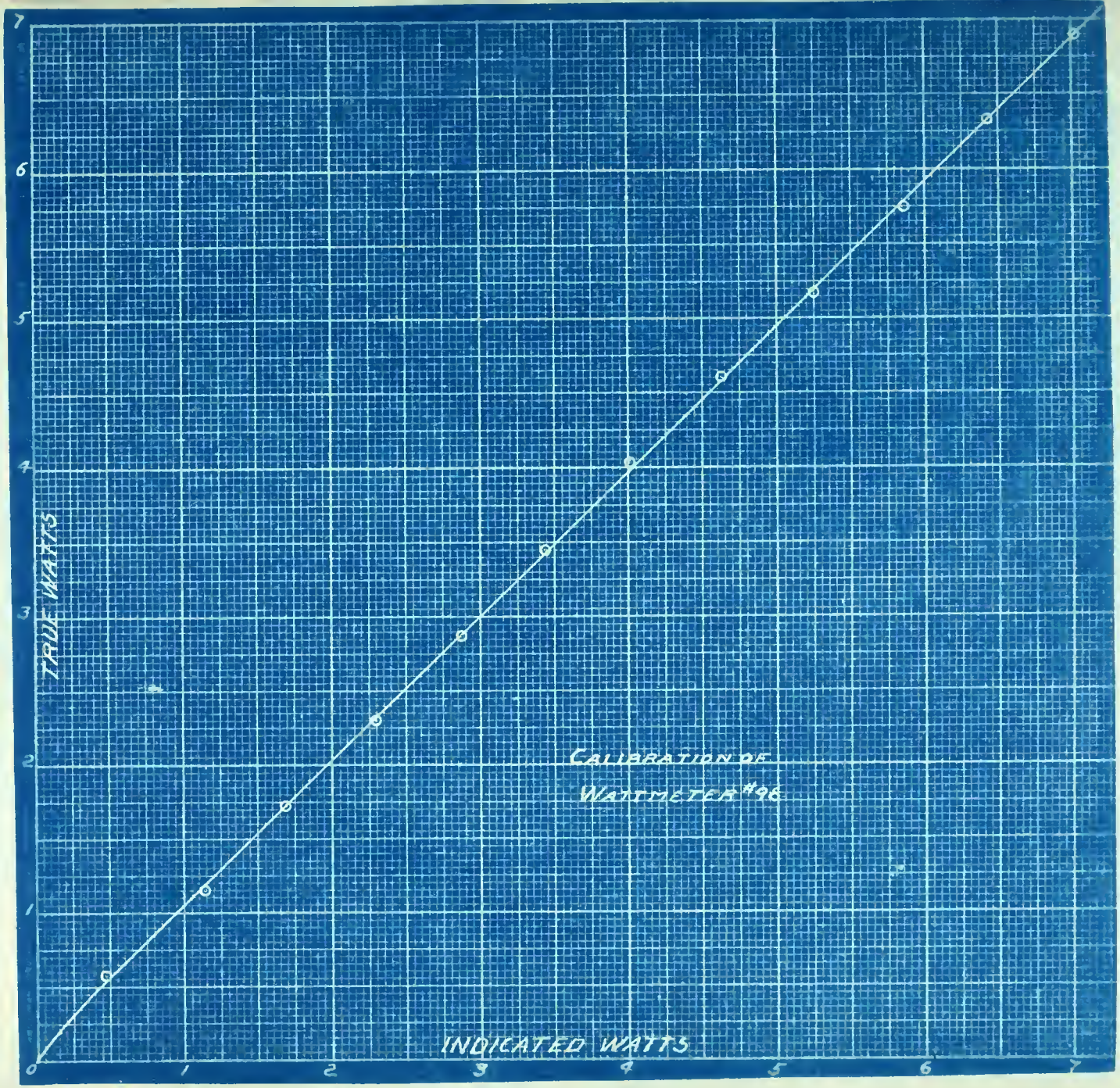
TRUE WATTS
INDICATED WATTS
CALIBRATION OF
WATTMETER #96
0
1
2
3
4
5
6
7

ARMOUR
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